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Civilian Radioactive Waste Management System
Management & Operating Contractor

Disruptive Events Process Model Report

TDR-NBS-MD-000002 REV 00 ICN 02

December 2000

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DISCLAIMER

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CHANGE HISTORY

Revision Number	Interim Change No.	Effective Date	Description of Change
00	00	04/00	Initial issue
00	01	07/00	Changes throughout as indicated by change bars. Causes for change include DOE comments, typographical errors, and completion of supporting documents.
00	02		Changes throughout as indicated by change bars. Causes for change include updating text to reflect no backfill, word processing changes and review comments, completion of supporting documents, and editorial changes to reference citations. The references listed below have been added to the reference list: • CRWMS M&O 2000d • CRWMS M&O 2000aa • CRWMS M&O 2000ab • CRWMS M&O 2000ac • Hill et al. 1998 • AP-2.21Q. The references listed below have been deleted from the reference list: • B00000000-01717-5700-00019 REV 00 (ACC: MOL.19980729.0050) • B00000000-01717-5700-00019 REV 00 (ACC: MOL.19980729.0052) • B00000000-01717-5700-00019 REV 00 (ACC: MOL.19980729.0047) • B00000000-01717-5700-00019 REV 00 (ACC: MOL.19980729.0049) • B00000000-01717-5700-00019 REV 00 (ACC: MOL.19980729.0051) • B00000000-01717-5700-00019 REV 00 (ACC: MOL.19980729.0053) • B00000000-01717-5700-00019 REV 00 (ACC: MOL.19980729.0048)

CHANGE HISTORY (Continued)

Revision Number	Interim Change No.	Effective Date	Description of Change
			The references listed below have been deleted from the reference list (continued): • TDP-WIS-MD-000003 REV 00 (ACC: MOL.19990811.0074) • TDP-CRW-GS-000005 (ACC: MOL.19991012.0150) • TDP-NBS-MD-000007 REV 00 (ACC: MOL.20000308.0236) • TDP-EBS-NU-000005 REV 00 (ACC: MOL.20000427.0323) • AP-SI.1Q (ACC: MOL.20000223.0508) • QAP-2-0 (ACC: MOL.19991109.0221). The references listed below have been updated with either ICN and/or REV information: • CRWMS M&O 2000b • CRWMS M&O 2000e • CRWMS M&O 2000h • CRWMS M&O 2000i • CRWMS M&O 2000k • CRWMS M&O 2000l • DOE 2000 • AP-3.10Q • AP-3.11Q • AP-3.12Q • AP-3.15Q . Section 3.1.7 has been added.

EXECUTIVE SUMMARY

The *Disruptive Events Process Model Report* (Disruptive Events PMR) summarizes the results of investigations intended to estimate the hazards to the potential repository at Yucca Mountain from events associated with the processes of volcanism and seismicity. The disruptive events analysis provides input to the Total System Performance Assessment-Site Recommendation (TSPA-SR) to support determination of the potential impacts these events might have on postclosure repository performance. Although information about the seismic characteristics of the site is essential for both preclosure and postclosure design for the potential repository, this report focuses on postclosure aspects, but recognizes that the postclosure analyses were based on the preclosure hazard analyses described in this report. Consideration of disruptive events is an essential element of the Repository Safety Strategy, which is needed for the License Application, and the U.S. Department of Energy Interim Guidance which contains descriptions of methods to be used to evaluate disruptive events for this purpose. Similarly, for the Site Recommendation, the Department of Energy's proposed 10 CFR 963 (64 FR 67054) specifies evaluating the postclosure suitability of the site using criteria that consider disruptive processes and events important to the total system performance of the site.

The Disruptive Events PMR considers igneous and seismic events. Criticality, which is listed as a disruptive event in proposed 10 CFR 963 (64 FR 67054), is not analyzed as a disruptive event in the current disruptive events analyses. Human intrusion will be analyzed separately from the primary total system performance assessment, as prescribed by regulation. The Repository Safety Strategy, in describing the postclosure safety case, includes a list of potentially disruptive processes and events. The definition of disruptive events for the Repository Safety Strategy follows proposed 10 CFR 963 (64 FR 67054). The Repository Safety Strategy list was developed from knowledge of the geologic setting, prominence in past technical reviews, and public concern. Potentially disruptive events in the Repository Safety Strategy include: human intrusion, water table rise to the level of the repository, seismic activity, igneous activity, waste-generated disruptions (including criticality), early failure of engineered barriers (caused by manufacturing defects), and drift collapse (rockfall). A section that describes disruptive events, not evaluated in this PMR, also discusses the treatment of these events for the TSPA-SR.

Disruptive events analysis for TSPA-SR is one in a series of such analyses supporting past performance assessments for the potential repository. These performance assessments, including disruptive events analysis, address technical concerns expressed by various oversight groups regarding performance of the potential repository during disruptive events. The Disruptive Events PMR, summarizing the results of supporting analyses, addresses these concerns, including those contained in U.S. Nuclear Regulatory Commission Issue Resolution Status Reports.

Disruptive events are treated in several ways in the TSPA-SR calculations. For dose consequence calculations, the TSPA-SR includes both nominal performance and disruptive events. Disruptive events are modeled as disruptive scenarios by modification of the appropriate subsystem elements and/or parameters in the TSPA-SR to reflect a change that represents a disruption of the nominal condition.

The Disruptive Events PMR summarizes the results of eight analysis model reports (AMRs) and one calculation that together analyze the potential consequences of two types of disruptive events: (1) volcanism (which includes both intrusive and extrusive occurrences); and (2) seismicity (vibratory ground motion) and associated structural deformation (fault displacement). Two AMRs summarized the results of expert elicitation projects to support characterization of the volcanic and seismic hazards at Yucca Mountain. These AMRs also presented the technical basis for assessing hazards related to volcanism, seismicity, and fault displacement. The two expert elicitation projects produced hazard curves for the annual probability and associated uncertainty of a volcanic event intersecting the repository and for the annual probability and associated uncertainty of exceedance of a range of ground motions and fault displacements. Although the expert elicitation results focused on hazard, the documentation contained consequence data that were used by several disruptive events AMRs.

Five AMRs and the calculation provided information about parameters needed to evaluate the effects, or geologic consequences, of the disruptive events. Analysis of disruptive events consequences was improved through literature research and interfacing with Yucca Mountain Site Characterization Project groups in the engineered barrier system (EBS) and waste package (WP) disciplines to produce descriptions of consequences to site structures, systems, and components. Another AMR was a compilation of screening arguments related to the features, events, and processes (FEPs) pertaining to disruptive events. These arguments provided, in part, the basis to support determination of the FEPs to be included in the TSPA-SR and the FEPs to be excluded based on analyses conducted outside the total system performance assessment and based on comparisons to regulatory criteria. The calculation took information from several AMRs and used the repository layout to calculate the number of waste packages affected by extrusive and intrusive igneous events.

Seismicity for the TSPA-SR is treated through uncertainty analysis of nominal performance, meaning it is treated as part of the nominal case. Screening (included in or excluded from TSPA-SR) of some individual disruptive events FEPs is supported by sensitivity calculations. The seismic events considered for the TSPA-SR include vibratory ground motion and fault displacement. These effects are characterized as annual probabilities of exceeding specified levels of ground motion or fault displacement. These ground motion and fault displacement characteristics are used to develop seismic design inputs for repository structures. For postclosure, ground motion is considered in terms of increased likelihood (frequency) of rockfalls in the emplacement drifts and possible damage to components of the EBS. Fault displacement effects are considered in terms of disruptions to components of the EBS and effects on the transport of radionuclides in the unsaturated zone.

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ACRONYMS AND ABBREVIATIONS

3-D	three-dimensional
AMR	analysis model report
DOE	U.S. Department of Energy
EBS	engineered barrier system
EDA II	Enhanced Design Alternative II
EPA	U.S. Environmental Protection Agency
FEP	feature, event, and process
HLW	high-level radioactive waste
ICN	Interim Change Notification
IRSR	Issue Resolution Status Report
KTI	key technical issue
LA	License Application
MTU	metric tons of uranium
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
PA	performance assessment
PMR	process model report
PSHA	Probabilistic Seismic Hazard Analyses
PVHA	Probabilistic Volcanic Hazard Analysis
QA	quality assurance
SSC	structure, system, and component
SNF	spent nuclear fuel
SR	Site Recommendation
SRSL	Site Recommendation Subsurface Layout
SZ	saturated zone
TBV	to be verified
TSPA	total system performance assessment
TSPA-SR	Total System Performance Assessment-Site Recommendation
TSPA-VA	Total System Performance Assessment-Viability Assessment

ACRONYMS AND ABBREVIATIONS (Continued)

UZ	unsaturated zone
VA	Viability Assessment
WP	waste package
YMP	Yucca Mountain Site Characterization Project

1. INTRODUCTION

To evaluate the postclosure performance of a potential repository at Yucca Mountain, a Total System Performance Assessment (TSPA) will be conducted. Nine documents, termed process model reports (PMRs), of which this document is one, have been developed to support the Total System Performance Assessment-Site Recommendation (TSPA-SR). TSPA is an ongoing iterative activity of the Yucca Mountain Site Characterization Project (YMP). The nine PMRs that support the TSPA-SR discuss the following topics:

- Integrated Site Model
- Unsaturated Zone Flow and Transport
- Near Field Environment
- Engineered Barrier System Degradation Flow and Transport
- Waste Package Degradation
- Waste Form Degradation
- Saturated Zone Flow and Transport
- Biosphere
- Disruptive Events.

These PMRs are supported by analysis model reports (AMRs) that contain the more detailed technical information that is summarized in each PMR and used for input to the TSPA. The technical information consists of data, models, software, analyses, and supporting documentation that are used to describe the applicability of each process model or disruptive events input for TSPA-SR. The PMR development process has the objective of ensuring the traceability of information from its source through the AMRs and PMRs and to the TSPA.

This Disruptive Events PMR summarizes conceptual models and technical product output that form part of the technical basis for the TSPA-SR. The AMRs supporting the Disruptive Events PMR provide inputs used to analyze the probable behavior of the natural system and the reference design engineered components in the presence of natural events that are considered to be "disruptive," as distinguished from "nominal" (expected conditions based on current site knowledge) in TSPA analysis (DOE [1999, Volume I, Section 5.2.3.5] for additional descriptions of disruptive and nominal events).

This Disruptive Events PMR summarizes the results of eight AMRs and one calculation that comprise the disruptive events analysis. Four of the AMRs and the calculation analyze the potential consequences of two types of disruptive events: (1) volcanism (both intrusive and extrusive); and (2) seismicity (vibratory ground motion), and structural deformation (fault displacement) (CRWMS M&O 2000a, 2000b, 2000c, 2000e, 2000g, 2000h, 2000i, 2000k, 2000l). Table 1-1 presents a list of these supporting documents. This PMR summarizes the results of analyses for interactions between these disruptive events and two designs for the potential repository: (1) Enhanced Design Alternative II (EDA II) (CRWMS M&O 1999a); and (2) Site Recommendation Subsurface Layout (SRSL) designs (CRWMS M&O 2000z). Four analyses (CRWMS M&O 2000b, 2000e, 2000h, 2000l) and the calculation (CRWMS M&O 2000k) were performed under the Interim Change Notification (ICN) process to address

Table 1-1. Eight AMRs and One Calculation Supporting the Disruptive Events PMR

AMR or Calculation	ID Number	DI Number	PMR Section
Features, Events, and Processes: Disruptive Events (CRWMS M&O 2000h)	T0010	ANL-WIS-MD-000005	2.1.4, 3.1.6, 3.2.4
Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (CRWMS M&O 2000b)	T0015	ANL-MGR-GS-000001	3.1.1
Characterize Eruptive Processes at Yucca Mountain, Nevada (CRWMS M&O 2000a)	T0025	ANL-MGR-GS-000002	3.1.2
Dike Propagation Near Drifts (CRWMS M&O 2000e)	T0020	ANL-WIS-MD-000015	3.1.3
Number of Waste Packages Hit by Igneous Intrusion (CRWMS M&O 2000k)	T0055	CAL-WIS-PA-000001	3.1.4
Igneous Consequence Modeling for TSPA-SR (CRWMS M&O 2000l)	T0070	ANL-WIS-MD-000017	3.1.5
Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada (CRWMS M&O 2000c)	T0075	ANL-CRW-GS-000003	3.2.1
Fault Displacement Effects on Transport in the Unsaturated Zone (CRWMS M&O 2000i)	T0090	ANL-NBS-HS-000020	3.2.2
Effects of Fault Displacement on Emplacement Drifts (CRWMS M&O 2000g)	T0115	ANL-EBS-GE-000004	3.2.3

the SRSL design (without backfill). One AMR (CRWMS M&O 2000i) was revised, in order to analyze the effects on flow and transport of fracture aperture change, using a more current version of the unsaturated zone (UZ) flow model. The results of that AMR will appear as new information in this PMR.

Two AMRs summarized the results of expert elicitation projects that provided the technical basis for assessing hazards related to volcanism, seismicity, and fault displacement (CRWMS M&O 2000b, 2000c). The two expert elicitations were reported in: *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada* (CRWMS M&O 1996) and *Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada* (Wong and Stepp 1998). The two expert elicitation projects produced estimates for the annual probability and associated uncertainty of a volcanic event intersecting the repository and for the annual probability and associated uncertainty of exceedance of a range of ground motions and fault displacements. Although the results of both expert elicitations focused on hazard, the documentation contained consequence information that was used by several disruptive events AMRs. The seismic hazard results were developed principally for preclosure analysis, however, they also provide the basis for the postclosure performance assessment (PA) analyses that are the focus of the Disruptive Events PMR. Disruptive events consequence analyses were improved through literature research and interfacing with YMP groups in the Engineered Barrier System (EBS) and waste package (WP) areas to produce consequence descriptions. One of the AMRs (CRWMS M&O 2000h) was a compilation of screening arguments regarding features, events, and processes (FEPs) relevant to disruptive events. These arguments supported determination of the FEPs to be included in TSPA-SR and the FEPs excluded based on analyses conducted outside the TSPA and based on comparisons to regulatory criteria. The calculation *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k) uses inputs from several AMRs to perform the calculation indicated by its title.

Defining the term "event" is important to determining probability and consequence, and to the resulting risk. In the term "disruptive events," the definition of event comes from FEPs as they relate to the natural barrier system. The following definitions for FEPs are from the *Total System Performance Assessment* Volume 3 of *Viability Assessment of a Repository at Yucca Mountain* (TSPA-VA) (DOE 1998a, Appendix A). Features are defined as "Physical, chemical, thermal, or temporal characteristics of the site or repository system." Events are defined as "(1) Occurrences that have a specific starting time and, usually, a duration shorter than the time being simulated in a model and (2) Uncertain occurrences that take place within a short time relative to the time frame of the model." Processes are defined as "Phenomena and activities that have gradual, continuous interactions with the system being modeled." An example of a feature of interest in disruptive events analysis is fractures. The influence of fault displacement on fracture aperture is analyzed in a disruptive events AMR (CRWMS M&O 2000i). Examples of events of interest in disruptive events analyses are igneous activity and earthquakes that cause volcanoes, igneous intrusions, ground motion, and fault displacement. An example of a process that produces events examined in disruptive events analysis is crustal extension in the Great Basin, which leads to earthquake events. It is important to note that the term event has been defined differently by different entities including the YMP, regulators, and expert elicitation projects. Inclusion of a comprehensive discussion of all of the ways in which this term, and others, are used in the numerous documents related to disruptive events is beyond the scope of this PMR; however, it is important to be aware that these differences exist.

Consequence is another term that is relevant to the discussion of disruptive events analysis and is defined in different ways by different entities. The TSPA-VA defines the term as "A measurable outcome of an event or process that, when combined with the probability of occurrence, gives risk" (DOE 1998a, Appendix A). Differences in definition of the term are related to differences regarding what is being changed by the "measurable outcome." For example, the consequence may be a change in dose (dose consequence), a change in the containment capacity of a natural or engineered system (consequence to an structures, systems, and component [SSC]), or a fault displacement (consequence of a geologic initiating event). As with the term event, it is important to be aware that these differences in definition of the term consequence exist; however, it is beyond the scope of this PMR to present a comprehensive compendium.

The definition of consequence uses the term risk which is defined in the TSPA-VA as "The probability that an undesirable event will occur multiplied by the consequences of the undesirable event" (DOE 1998a, Appendix A). For disruptive events analysis, probability is provided by the results of expert elicitation (CRWMS M&O 1996; Wong and Stepp 1998). Consequence information is provided by both disruptive events analysis and work from other organizations (see Figure 1-1), and risk is calculated downstream of disruptive events analysis by TSPA-SR. The term hazard is similar to the term consequence and is used by the two expert elicitations (Probabilistic Volcanic Hazard Analysis [PVHA] and Probabilistic Seismic Hazard Analyses [PSHA]) that have hazard curves as their results. Examination of these documents shows that hazard is used to describe the probability of occurrence of an event that has potential consequences.

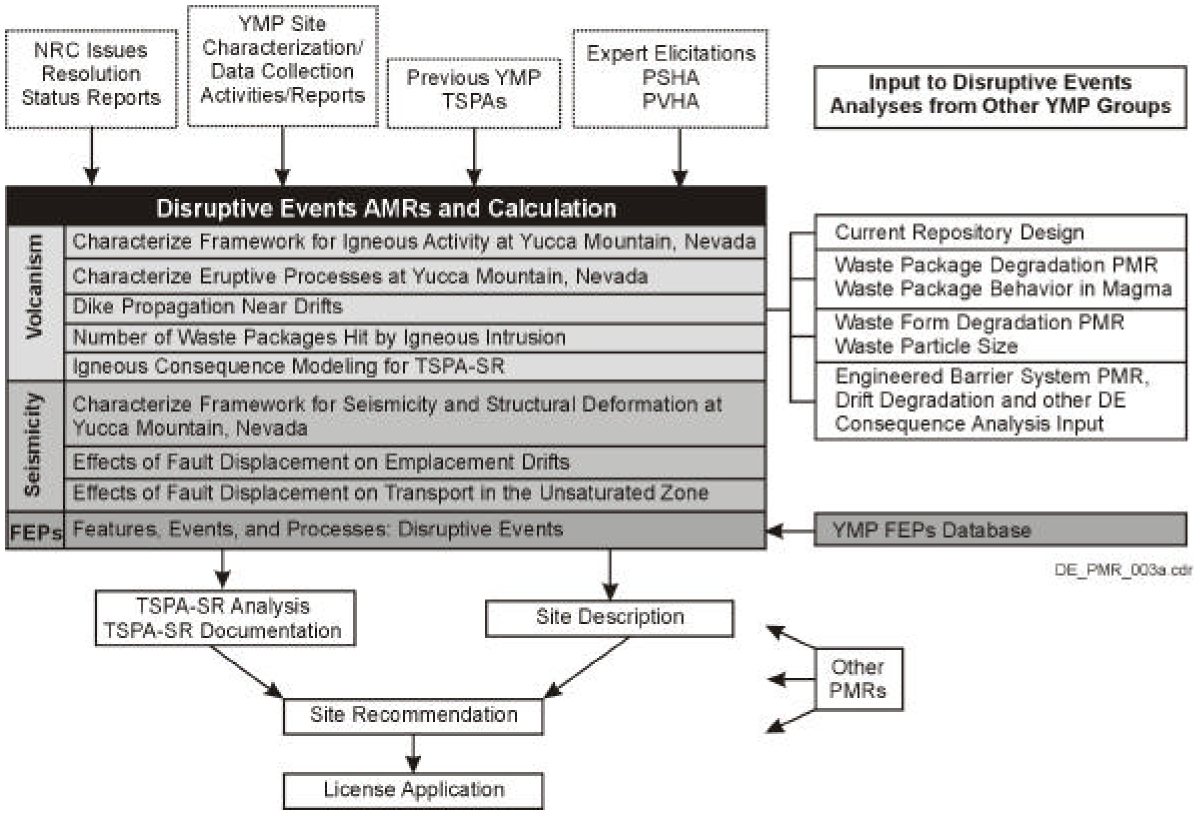


Figure 1-1. Relationship Between Key YMP Documents, Disruptive Events Analyses and Inputs to Disruptive Events Analyses from Analyses under Other PMRs; Data Flow from Top to Bottom; Documents at Top Providing Inputs to Disruptive Events Analyses Also Support Other Analyses

PAs are concerned with the effects of events that are often defined in relation to the probability of damage to site SSCs. For design and preclosure performance purposes, YMP design basis events include damage to SSCs, with frequency category 1 events (1 occurrence/1,000 years) being normal (nominal) conditions and frequency category 2 events (1 occurrence/10,000 years) being unlikely but credible events that would challenge design capabilities for containment (proposed 10 CFR 63 [64 FR 8640]). Because there is a need to relate the tolerance of SSCs to ground motion and fault displacement events, the expert elicitation for seismicity produced hazard curves that describe the annual probabilities of exceedance of specified levels of ground motion or fault displacement. These hazard curves provide the basis to develop the design inputs for SSCs that must withstand specified design basis events.

For TSPA, a disruptive event is defined as an event that has a “significant” consequence and a probability of occurrence of at least one in ten thousand, but less than one, in the first ten thousand years after closure of the potential repository—or approximately a 10^{-8} annual probability of occurrence for events that occur at a constant rate (DOE 1998a, pp. 4-81 and A-12; Dyer 1999, Sections 114e, 114f). TSPA must evaluate specific FEPs of the geologic setting in deciding whether the magnitude and timing of the resulting expected annual dose would be significantly changed by their omission. Disruptive events are those that could either directly cause release of radionuclides or alter the nominal behavior of the repository system. Guidance for exclusion from TSPA analysis of events having less than a 10^{-8} annual probability of occurrence comes from the U.S. Department of Energy's (DOE's) "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01; July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999; hereafter referred to as DOE's Interim Guidance). DOE's Interim Guidance (Dyer 1999, Sections 114e, 114f) uses, but does not define, the term "significant" with respect to consequence. Disruptive events analysis for this report focuses on the postclosure period, which must include events having as low an annual probability as 10^{-8}.

The TSPA-VA considered four events disruptive: basaltic igneous activity, seismic activity, nuclear criticality, and inadvertent human intrusion (DOE 1998a, p. 4-80). For TSPA-SR, disruptive events analysis includes a more focused analysis of the two basaltic igneous activity scenarios analyzed in TSPA-VA. TSPA-SR also includes analysis of seismic activity as a nominal event, given the high probability of seismic activity of some magnitude during the next 10,000 years. As explained in Section 3.3 of this Disruptive Events PMR, the YMP is conducting ongoing studies to develop seismic design inputs for the repository SSCs. Potential fault displacement effects on emplacement drifts and on transport in the UZ are analyzed as part of this Disruptive Events PMR in support of TSPA-SR.

For TSPA-SR, human intrusion is not modeled as a disruptive event. It is analyzed separately from probabilistic TSPA analysis, but will be modeled using the TSPA model. The DOE's Interim Guidance describes human intrusion as a stylized event assigned prescribed conditions such as an open drill hole through a WP that continues to the water table (Dyer 1999, Section 113d). Criticality was shown by the TSPA-VA analysis to be of low consequence. Criticality will be treated in a future version of the YMP FEPs database.

At the time the initial development plans for the disruptive events AMRs were produced, the design did not include drip shields or backfill. The disruptive events analysis for ground motion (seismicity), therefore, included potential damage to WPs from rockfall. The analysis for the TSPA-VA, which was based on a design with no backfill and no drip shields, also treated rockfall resulting from an earthquake as a disruptive event. However, when backfill and drip shields were added to the proposed design, the TSPA-SR analysis indicated that rockfall could be screened out of the TSPA on the basis of low consequence. For the design that includes dripshields but no backfill, analysis indicates that rockfall is still of low consequence and can be screened out of consideration. Further enhancements to the drip shield design have led to a reconsideration of the need to include ground motion damage to the drip shield in the TSPA-SR. At the time of production of this PMR, analysis was still ongoing.

Chapter 1 of this report begins with the definition of "disruptive events" and a description of which events will be analyzed for TSPA-SR. Chapter 1 continues with (1) descriptions of the objectives and scope of the report; (2) the quality assurance (QA) under which analyses, calculations, and documentation were performed; and (3) the relationship of this report to analyses in other PMRs and key project documents. Chapter 2 provides a discussion of previous work leading to the present analyses and calculations; it presents a summary level discussion of the approach to disruptive events analysis for TSPA-SR. Chapter 3 provides a summary level discussion of the results of the analyses and the calculation that support this Disruptive Events PMR; it includes a discussion of alternative conceptual models. Chapter 3 also contains a brief discussion of how disruptive events analyses address issues from the various oversight groups.

Chapter 4 contains roadmapping of disruptive events analyses and calculations to NRC key technical issues (KTIs) and acceptance criteria from various Issue Resolution Status Reports (IRSRs). Chapter 5 presents a summary, and Chapter 6 identifies the references cited in the report.

1.1 OBJECTIVES

All PMRs have the shared objective of documenting the necessary and sufficient technical information that the YMP will rely upon to make its site suitability evaluation and potential licensing argument. Specific reports, which cover designated technical topics, are "stand alone" reports. The purpose, objectives, and scope of this Disruptive Events PMR are contained in the associated technical product development plan (CRWMS M&O 2000d) and are described below.

Objectives for this Disruptive Events PMR include summarizing the results of the supporting analyses and the approach to and results of FEPs screening for disruptive events; providing historical information on disruptive events analyses; and discussing how information contained in the report, or the associated AMRs, addresses issues raised by the NRC and other oversight groups (see Section 3.3). The report provides the overview framework for why the AMRs for disruptive events were initiated and where and how the results were used, including their uses in the TSPA-SR. This Disruptive Events PMR contains discussion of the treatment of disruptive events in previous TSPAs to support traceability of the history of this analysis. The report documents the exchange of information between different organizations and provides consistency of approach between the analyses within this Disruptive Events PMR and those performed for similar events by other organizations, especially those analyzing preclosure EBSs and WPs. The report enhances defensibility, traceability, and transparency of the supporting analyses and calculations by placing them in context with each other and other PMR analyses. An objective of the report is to clarify the bases for project comments on specific NRC KTIs and acceptance criteria. Also documented is consideration of alternative conceptual models proposed by the NRC and other oversight groups and by non-project researchers who developed new information for consideration since completion of the two expert elicitation projects (PSHA and PVHA).

1.2 SCOPE

This document summarizes information from the following activities and provides roadmapping to link the analyses to each other and to key issues or YMP requirements identified below. These tasks include:

1. Summarize the analysis of disruptive events for TSPA-SR and provide pointers to the history of how analyses have evolved through past TSPAs.

2. Link current analyses to KTIs and acceptance criteria described in NRC IRSRs and link improvements in the current approach for evaluating disruptive events to technical reviews of previous TSPAs.

3. Summarize how disruptive events analyses and the probabilities and uncertainties of those disruptive events will be incorporated in the TSPA-SR analysis.

4. Provide a high level discussion of conceptual model evaluations and probability distributions produced by expert elicitation projects and explain how the documentation of these studies is used and augmented to support consequence analysis of impacts on engineered and natural barriers.

5. Summarize the role of the current analyses as a step in the continued development of scenarios and screening of FEPs to meet NRC requirements.

6. Support demonstration of the thoroughness and completeness of model selection through examination of alternative model concepts and provide roadmapping to more detailed evaluation of the conceptual models and data used in the current approach.

7. Describe the procedure for ensuring that new data are assessed for impacts on the conceptual models and modeling approach for disruptive events.

8. Discuss impacts of design changes on the modeling approach for disruptive events.

9. Provide a summary of the YMP QA procedural framework guiding development of this PMR and the supporting AMRs and calculations, and describe the impact of Process Validation and Reengineering.

1.3 QUALITY ASSURANCE FOR DISRUPTIVE EVENTS ANALYSES AND THE DISRUPTIVE EVENTS PMR

Pursuant to evaluations performed in accordance with AP-2.21Q, *Quality Determinations and Planning for Scientific, Engineering, and Regulatory Compliance Activities*, it was determined that activities supporting development of this Disruptive Events PMR and its documentation were quality affecting activities subject to the QA requirements of the *Quality Assurance Requirements and Description* (DOE 2000). The Disruptive Events PMR was prepared according to the associated technical work plan (CRWMS M&O 2000d) and complies with DOE Interim Guidance (Dyer 1999).

This Disruptive Events PMR was prepared in accordance with AP-3.11Q, *Technical Reports*, and reviewed in accordance with AP-2.14Q, *Review of Technical Products*. The QA procedures under which the supporting AMRs and one calculation were prepared are described in the AMRs and calculation and their respective planning documents. The primary procedure under which the AMRs were prepared is AP-3.10Q, *Analyses and Models*, and the procedure for the calculation was AP-3.12Q, *Calculations*.

Qualified data used in those AMRs were qualified in accordance with AP-SIII.2Q, *Qualification of Unqualified Data and the Documentation of Rationale for Accepted Data*. Information used in this report has been managed, and the quality status of it tracked, in accordance with AP-3.15Q, *Managing Technical Product Inputs*.

1.4 RELATIONSHIP OF DISRUPTIVE EVENTS PMR TO WORK UNDER OTHER PMRs AND KEY PROJECT DOCUMENTS

As stated in Section 1.1, this Disruptive Events PMR is one of several upper level documents (the PMRs) that summarize the analyses, models, and calculations that contribute to the TSPA-SR. The relationship of this Disruptive Events PMR to the PMRs from which data were received, the TSPA-SR, Site Recommendation (SR), and the License Application (LA) is shown in Figure 1-1. This PMR directly supports the development of descriptive material needed for SR and LA and also supports the development of TSPA calculations, which are needed to evaluate the postclosure performance of the potential repository.

This report describes how various site characterization activities are used in the disruptive events analysis (Section 2.1). These documents included the S*ite Characterization Plan Yucca Mountain Site, Nevada Research and Development Area, Nevada* (DOE 1988) and the *Yucca Mountain Site Description* (CRWMS M&O 2000ab). Two YMP expert elicitations that produced hazard analyses for volcanism, ground motion, and fault displacement also contain evaluations of the geologic framework and FEPs that are characteristic of the site (CRWMS M&O 1996; Wong and Stepp 1998). Chapter 2 also describes the role of previous TSPAs in shaping the type of disruptive events analysis that was performed for TSPA-SR. The TSPA documents are listed in Section 2.1.

As shown in Figure 1-1, TSPA-SR analysis required SSC consequence information to support disruptive events analyses that was, in large part, provided by data and analyses from other PMRs. The AMR *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2000o), which supported the *Waste Form Degradation Process Model Report* (CRWMS M&O 2000t), contains an analysis that provides waste particle size information to support analyses of volcanic eruption in the disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l). The *Waste Package Degradation Process Model Report* (CRWMS M&O 2000u) provided information, through the calculation *Waste Package Behavior in Magma* (CRWMS M&O 1999b), on the behavior of a WP in the thermal environment caused by magma in an emplacement drift. TSPA-SR will require inputs from other PMRs for analyses downstream of the Disruptive Events PMR analyses to support the final output for TSPA-SR. These inputs include the supporting analyses in the Biosphere PMR *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000s) and *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2000m). The drip shield damage abstraction in the AMR *EBS Radionuclide Transport Abstraction* (CRWMS M&O 2000r) provided by the PA group will feed into TSPA-SR downstream of the disruptive events AMRs. Repository design information was provided by the EDA II (CRWMS M&O 1999a), SRSL (CRWMS M&O 2000z) and TSPA-VA, Volume 2 (DOE 1998b).

2. PREVIOUS DISRUPTIVE EVENTS WORK AND TSPA APPROACH FOR SR

This Disruptive Events PMR summarizes the results of analyses and one calculation that will support TSPA-SR. TSPA is a risk assessment that quantitatively estimates how the potential Yucca Mountain repository system will perform in the future under the influence of specific FEPs, incorporating uncertainty in the models and data (DOE 1998a, p. A-41). The purpose of TSPA is to:

1. Provide the basis for forecasting system behavior and testing that behavior against safety measures in the form of regulatory standards

2. Provide the results of TSPA analyses and sensitivity studies

3. Provide guidance to site characterization and repository design activities

4. Through analysis of events that could affect performance, support selection of the most effective design options.

Analyses in past TSPAs and in the TSPA-SR included disruptive events that could compromise the waste isolation function of the natural and EBSs. Disruptive events analyses were developed in association with studies from groups analyzing the EBS of the potential repository, including emplacement drifts, WPs, and waste forms. By working with these groups, disruptive events incorporated analyses of responses of SSCs.

The history of past disruptive events analyses is contained in previous TSPAs performed by the YMP. Although the term "disruptive events" was not used in the earlier documents, and the processes analyzed as "disruptive" have changed over time, these analyses have included volcanism and seismicity, fault displacement, water table rise, early failure of engineered barriers such as cladding or drip shields, drift collapse, criticality, and human intrusion. These TSPAs include Sinnock et al. (1984), Barnard and Dockery (1991), Barnard et al. (1992), Eslinger et al. (1993), Wilson et al. (1994), CRWMS M&O (1994, 1995), and DOE (1998a). These TSPAs have contributed to the iterative development of the PA process, including disruptive events analysis. An explanation of the TSPA process (which includes disruptive events analyses) can be found in the TSPA-VA documentation (DOE 1998a, pp. 1-1 to 1-8). The manner in which disruptive events analyses were treated in TSPA-VA is discussed in Section 2.1 of this Disruptive Events PMR. The summary level approach for disruptive events analysis for TSPA-SR is discussed in Section 2.2, and a more detailed summary of these analyses is provided in Chapter 3 of this PMR.

Disruptive events have been evaluated in several ways for TSPA calculations. Both nominal and disruptive events are defined in Chapter 1 of this PMR. Disruptive events have been modeled as disruptive scenarios by modification of the appropriate subsystem elements and/or parameters to reflect a change that represents a disruption of the nominal condition. As discussed in Section 3.2.4, most effects of seismic hazards have been shown to have no significant effects on overall performance and are not included in the TSPA-SR. Effects of seismic hazards that are included in the TSPA-SR are included as part of the nominal case. Screening of some individual disruptive events FEPs is supported by sensitivity calculations. An example is the analysis during TSPA-VA that supported screening out the effects of significant alteration of groundwater flow patterns by a basaltic dike intrusion into the saturated zone (SZ) (indirect effects of volcanism). Sensitivity studies showed no significant effects (CRWMS M&O 1998b, p. 10-55). Subsequent examination of the indirect effects of the volcanism scenario during TSPA-SR FEPs screening also supports screening out this scenario (see Section 3.1.6 of Disruptive Events PMR).

The following sections of Chapter 2 provide information to facilitate understanding of the geologic framework and processes at Yucca Mountain that produced the events analyzed and summarized in this PMR. Previous YMP work describing FEPs for volcanic and seismic hazards is described, as are the results of disruptive events analyses of these FEPs for TSPA-VA. The evolution of the set of scenarios analyzed in the AMR *Features, Events, and Processes: Disruptive Events* and the overall FEPs process are discussed at a summary level. Chapter 2 closes with a discussion of the general disruptive events analysis approach.

2.1 PREVIOUS YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT GEOLOGIC WORK RELATED TO DISRUPTIVE EVENTS

The analysis of disruptive events was based on the geologic framework developed from the intensive investigations conducted to characterize the geologic setting of the Yucca Mountain region. Site characterization studies have led to the development of the geologic framework described in the following subsections. It is through these studies that the geologic FEPs of importance to volcanism, ground motion, and fault displacement have been described. The site descriptions and AMRs contain the conceptual models of the processes related to volcanic and seismic hazards.

2.1.1 Yucca Mountain Geologic Framework

This section provides a summary level discussion, based on past YMP work, of the regional setting, stratigraphy, and structural features that form the geologic framework of Yucca Mountain. Section 2.1.2 focuses on past geologic studies related to Yucca Mountain region volcanism, and Section 2.1.3 focuses on past geologic studies related to Yucca Mountain region seismicity and structural deformation. These three sections summarize the geologic picture for the Yucca Mountain region that has been developed and provides a foundation for disruptive events analyses for TSPA-SR. A comprehensive description of the site geology is presented in the *Yucca Mountain Site Description* (CRWMS M&O 2000ab). The following discussion is based on this document unless otherwise noted. The Yucca Mountain site is located on the western boundary of the Nevada Test Site (NTS), where scientists have conducted geologic investigations since the 1950s. Studies related to nuclear waste disposal have focused on Yucca Mountain since the late 1970s and have included mapping of the rocks at the surface and the subsurface, drilling and logging of numerous wells and boreholes. The characterization of the geology of Yucca Mountain is nearing completion, and it provides the framework for understanding the natural processes important to assessment of disruptive events and the safety of the potential repository.

Yucca Mountain is located within the region of the western United States known as the Great Basin. Three regional tectonic domains (distinctive, structurally bounded blocks of the Earth's crust) characterize Yucca Mountain and its surrounding environs. These regions are the Walker

Lane domain which includes the potential repository site, the Basin and Range domain to the northeast, and the Inyo-Mono domain to the southwest (CRWMS M&O 2000ab, Section 4.2.1). The Walker Lane domain is characterized by a series of crustal blocks separated by discontinuous northwest striking and northeast striking strike-slip faults. In southern Nevada, including Yucca Mountain, the pattern of mountains and valleys has been formed in the past 15 million years from the movement of faults on one or both sides of the mountain ranges (Fridrich 1999).

2.1.1.1 Yucca Mountain Regional Stratigraphy

The geologic system at Yucca Mountian forms a fundamental framework for understanding the performance of the site as a potential geologic repository for high-level nuclear waste. The exposed stratigraphic sequence at Yucca Mountain is dominated by mid-Tertiary volcanic rocks, consisting mostly of pyroclastic flow and fallout tephra deposits with minor lava flows and reworked materials (CRWMS M&O 2000ab, Section 4.5.1). Rocks and sedimentary deposits exposed in the region surrounding Yucca Mountain range from Precambrian, or more than 570 million years old, to surficial Holocene deposits, or less than about 10,000 years old. However, with the exception of two limited areas, Calico Hills and Bare Mountain, surface outcrops in the potential repository site area range from Miocene to Recent (Day et al. 1998). Understanding the distribution of rock types is important because it enables geologists to understand the geologic history of the area, which is fundamental to analyses of geologic hazards such as seismic and volcanic risk. Rock types below and around Yucca Mountain influence the regional flow of groundwater and directly control the migration of any potential releases from the repository system.

The stratigraphic sequence of volcanic rocks at Yucca Mountain is the result of two stages of regional volcanism, an early silicic and a later basaltic stage. Between about 15 and 7.5 million years ago, during the Miocene Epoch of the Cenozoic Era, a series of large-scale silicic volcanic eruptions resulted in the formation of the southwestern Nevada volcanic field (CRWMS M&O 2000ab, Section 12.2.4), which consists of six major volcanic centers, or "calderas," in which Yucca Mountain is located. The Timber Mountain Caldera Complex, one of six major calderas in the southwestern Nevada volcanic field, includes the Claim Canyon Caldera located north of Yucca Mountain. The silicic caldera-forming eruptions occurred during a period of intense tectonic activity associated with active faulting caused by rapid extension of the earth's crust. The Claim Canyon Caldera was the probable eruptive source of the approximately 13-million-year-old rock units that now form the mountain ridges at the potential repository site. These eruptions, along with all of the silicic activity from the southwest Nevada volcanic field, ended over seven million years ago.

Volcanism that was predominantly basaltic began in the region approximately 11 million years ago and has continued into the Quaternary period. The basaltic volcanic events were much smaller in magnitude and less explosive than those of the silicic episode. Two episodes of basaltic volcanism have occurred. An older episode of basaltic volcanism occurred between about 9 and 7.3 million years ago, while a second one occurred between about 4.8 and 0.08 million years ago (CRWMS M&O 2000ab, Section 4.3.2.3). The more recent events consisted of small volume volcanoes, in the form of cinder cones with lava flows and volcanic ash, that erupted to the west and south of Yucca Mountain. Four cinder cones formed about

1 million years ago in Crater Flat, west of Yucca Mountain. The latest volcanic episode, about 80,000 years ago, created the Lathrop Wells Cone, about 16 km (10 mi) south of the potential repository site. Additional detail on the Miocene to Quaternary volcanic history of the Yucca Mountain region is provided in CRWMS M&O (2000ab, Section 12.2.2).

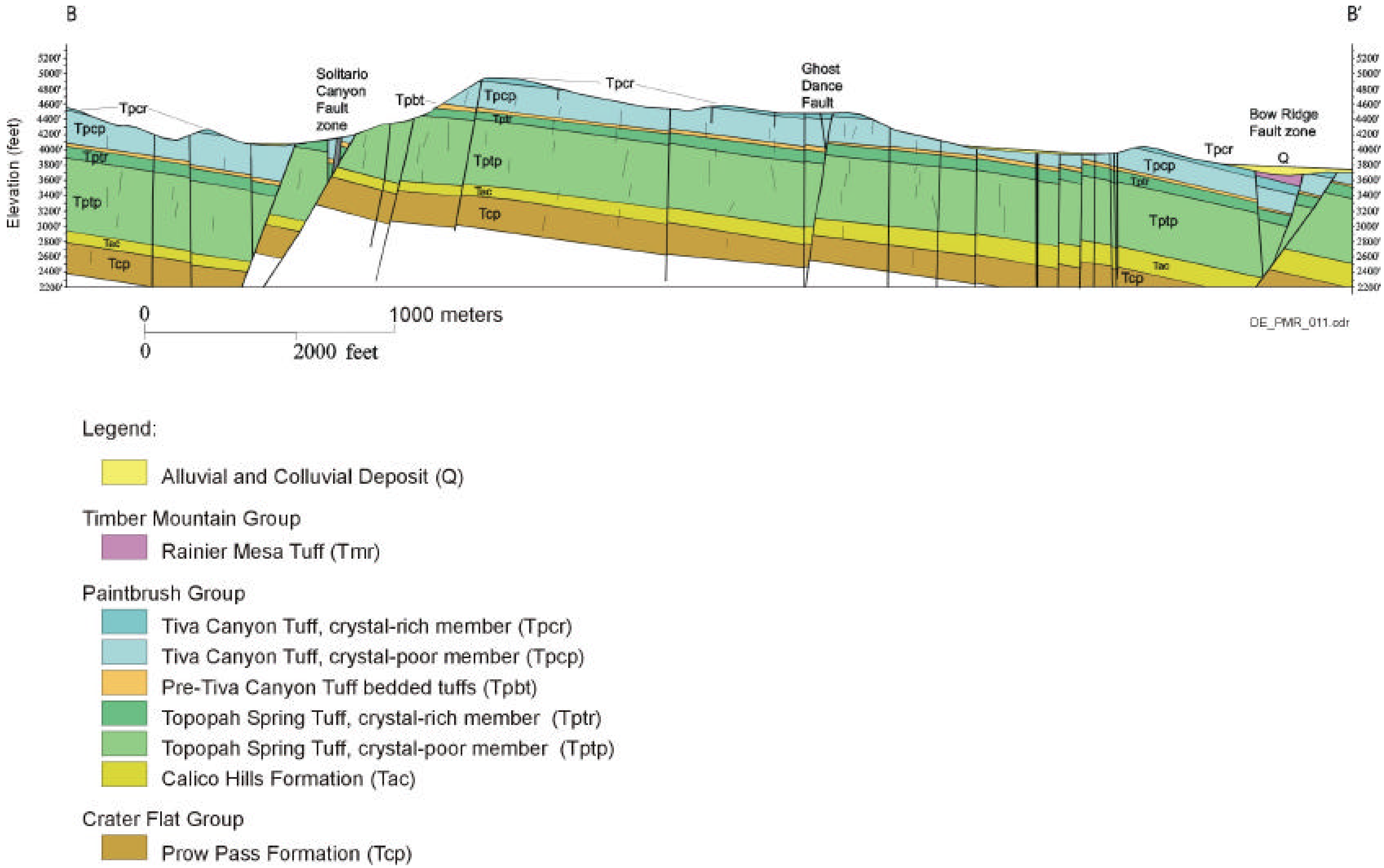
Surficial deposits in the Yucca Mountain region provide a record of the evolution of surface processes and climate conditions over the past several hundred thousand years (CRWMS M&O 2000ab, Section 4.4.3.3). Most surficial deposits are composed of sands and gravels, known as alluvium if they are deposited by flowing streams or as colluvium if they originate from hill slopes as flows of debris. Eolian deposits (wind-blown deposits, such as sand dunes) are generally a minor component of the surficial deposits in the region. The ages of surficial deposits range from less than 1,000 years to more than 760,000 years, but most deposits exposed at the surface were deposited during the last 100,000 years. Determining the ages and distributions of these deposits is important to understanding the age and movement of faults in the area.

2.1.1.2 Yucca Mountain Site Stratigraphy

Yucca Mountain consists of successive layers of volcanic rocks that generally thin from north to south. These rocks are described in detail in the *Yucca Mountain Site Description* (CRWMS M&O 2000ab, Section 4.5.4). Three volcanic tuff layers are present between the surface and the elevation of the potential repository: the Tiva Canyon welded tuff at the surface, the Topopah Spring welded tuff at the level of the potential repository, and an intervening nonwelded tuff. As a result of faulting over the last 13 million years, these layers are all tilted to the east about 10 degrees. Figure 2-1 shows these tilted volcanic tuffs. Most of the surface of Yucca Mountain above the potential repository location is composed of the Tiva Canyon Tuff of the Paintbrush Group. This unit is a large-volume, regionally extensive ash-flow tuff with a thickness that ranges from 50 to 175 m (165 to 575 ft).

A layer of nonwelded tuff underlies the Tiva Canyon Tuff near the site of the potential repository. The nonwelded layer includes two separate ash flows, the Yucca Mountain Tuff and the Pah Canyon Tuff. In the vicinity of the potential repository the total thickness of the nonwelded units ranges from 30 to 50 m (100 to 165 ft).

The lowermost unit in the Paintbrush Group is the Topopah Spring Tuff, which forms the host rock for the potential repository (CRWMS M&O 2000ab, Section 4.5.4.7.1). The Topopah Spring Tuff has a maximum thickness of about 380 m (1,250 ft) near Yucca Mountain. Based on surface mapping and studies of boreholes and underground exposures, the Topopah Spring Tuff has been subdivided into several lateral layers according to chemical composition, mineral content, the size and abundance of pumice and rock fragments, and other variations in texture and appearance. An important characteristic of the layers is the presence and abundance of lithophysae, which are bubble-like holes in the rock caused by volcanic gases that were trapped in the rock matrix as the ash-flow tuff cooled. The nature, size, and abundance of lithophysae in tuff may affect its thermal, mechanical, and hydrologic properties.



Source: Modified from CRWMS M&O 2000ab, Figure 4.6-6.

Figure 2-1. Tilted Volcanic Tuffs of Yucca Mountain

The lower and middle portions of the Topopah Spring Tuff have been divided into four layers according to the amount of lithophysae they contain. Because these layers are tilted, and the drifts in the potential repository would be near-horizontal, the potential repository horizon crosses the lithophysal zones. Like the Tiva Canyon Tuff, the Topopah Spring Tuff is fractured throughout, and these fractures provide the main pathway for groundwater to flow through the rock unit. Beneath the Paintbrush Group, the Calico Hills Formation is a series of mostly nonwelded rhyolite tuffs and lavas. The formation thins southward across the potential repository site, from a total thickness of as much as 460 m (1,500 ft) to only about 15 m (50 ft) (CRWMS M&O 2000ab, Section 4.5.4.6). The water table below the potential repository is located within the Calico Hills Formation.

The geologic units below the water table contain volcanic rocks composed mainly of welded and nonwelded ash-flow tuffs of the Crater Flat Group and older undifferentiated Miocene volcanics. The volcanic rocks are underlain by Paleozoic limestones and dolomites. Although the older volcanic rocks and the Paleozoic rocks lie deep beneath the surface near Yucca Mountain, they are found at much shallower depths (and even at the surface) to the south, where they are an important component of the hydrologic flow system.

2.1.1.3 Yucca Mountain Faulting and Local Structural Geology

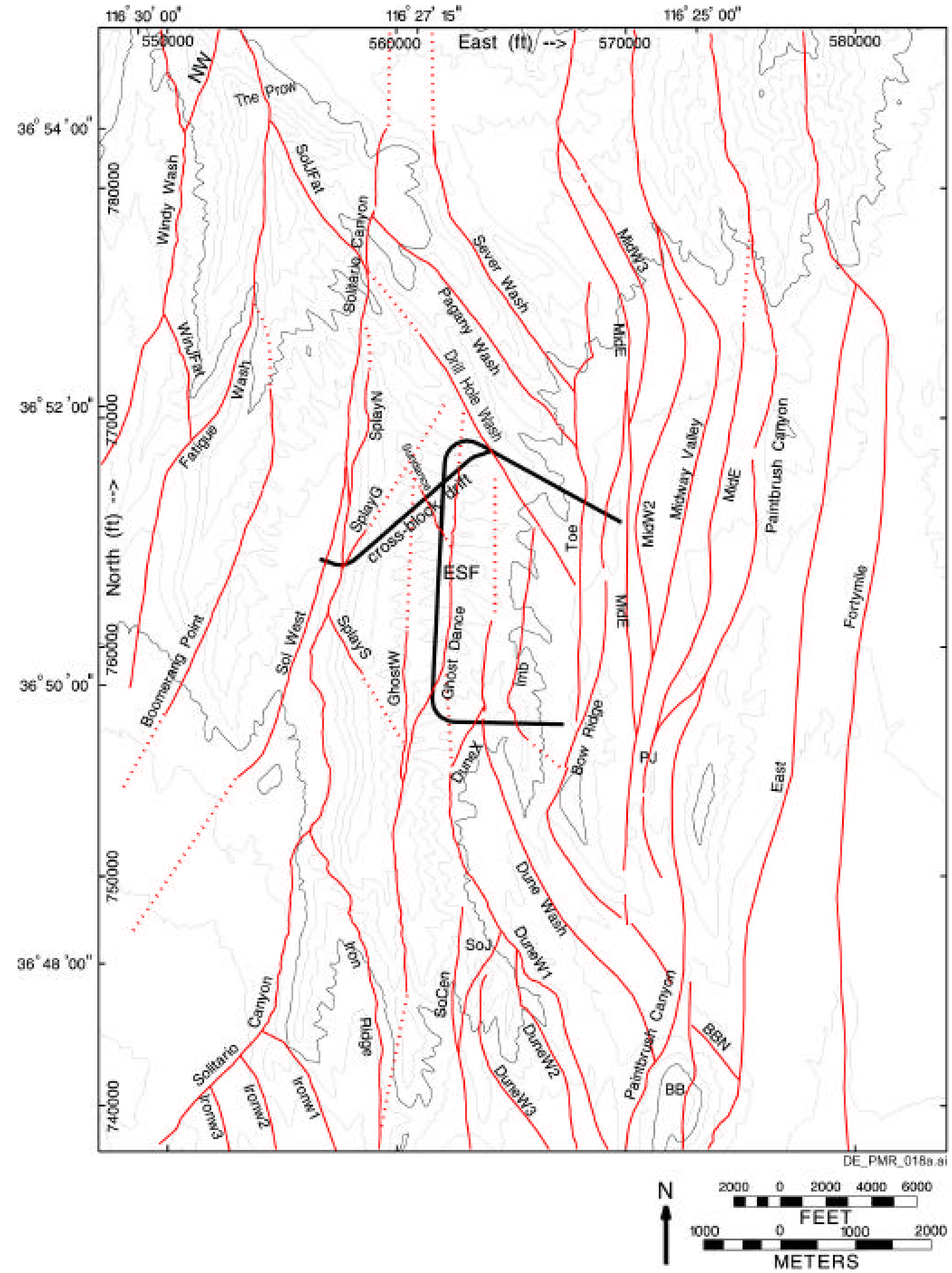
The distribution and properties of faults and fractures in the volcanic bedrock are important elements of the structural geology of the potential repository at Yucca Mountain. The potential main repository emplacement area is bounded on the west by the Solitario Canyon fault and on the east by the Ghost Dance fault. No faults with significant displacement (more than a few meters) occur within the area defined for emplacement (Wong and Stepp 1998). Detailed studies of the faults within the emplacement area indicate that they are not active faults; thus they are considered to have an extremely low probability of being active in the future (CRWMS M&O 2000c, Section 6.3.2).

The structural geology of Yucca Mountain is dominated by block-bounding faults spaced 1 to 4 km (0.6 to 2.5 mi) apart. These faults include (from west to east) the Windy Wash, Fatigue Wash, Solitario Canyon, Bow Ridge, and Paintbrush Canyon faults (see Figure 2-2). The faults generally are steeply dipping, north-south striking normal faults, and typically exhibit some left-lateral displacement.

Displacement between the block-bounding faults occurs along multiple smaller faults, which may intersect block-bounding faults at oblique angles. The Ghost Dance and Sundance faults are examples of smaller "intrablock" faults near the potential repository.

2.1.1.4 Yucca Mountain Fracture Characteristics

The distribution and characteristics of fractures at Yucca Mountain are important, because in many of the hydrogeologic units at the site (particularly the welded tuffs) fractures are the dominant pathways for groundwater flow in both the UZ and SZ. The fracture systems play a major role in the performance of the potential repository. The following discussion was summarized primarily from Section 4 of the *Yucca Mountain Site Description* (CRWMS M&O 2000ab, Section 4.6.6).



Source: CRWMS M&O 2000w

NOTES: Fault names shown here are for the Geologic Framework Model (GFM3.1) modeling purposes only and have no impact to the discussion presented in this PMR. Fault Trace Inputs, dotted where fault is buried or extended. ESF = Exploratory Studies Facility.

Figure 2-2. Structural Geologic Map of the Yucca Mountain Area in the Vicinity of the Exploratory Studies Facility

Fractures at Yucca Mountain are generally of three types: early cooling joints, later tectonic joints caused by faulting and rock stress, and joints caused by erosional unloading. At Yucca Mountain, cooling and tectonic joints have similar orientations but can be distinguished from each other because cooling joints are smoother. Cooling joints form two orthogonal (at 90° angles to each other) sets of steeply dipping fractures and, locally, a set of subhorizontal fractures. Four steeply dipping sets and one subhorizontal set of tectonic joints have been identified. In general, joint orientation is significant in disruptive events analyses; the relationship between the orientation of emplacement drifts and joint and fault orientations has an effect on rockfall. Joint orientation, which affects the size and number of key blocks, controls the rock sizes, shapes, and numbers that can fall (CRWMS M&O 2000f).

Fracture density, connectivity, and hydraulic conductivity are highest in the densely welded tuffs and lowest in the nonwelded units. The Tiva Canyon and Topopah Spring welded units are characterized by well-connected fracture networks, whereas the Paintbrush nonwelded units and the Calico Hills tuffs generally do not exhibit connected fractures. Additionally, the non-lithophysal welded units tend to have fractures with longer trace lengths, while the units with higher lithophysal content tend to have fractures with shorter trace lengths. It is reasoned that the presence of lithophysae inhibits the propagation of fractures (Sweetkind et al. 1997, pp. 61 to 66). In all units fracture density varies both vertically and laterally because of the variation in tuff properties.

Fractures related to faults may affect the hydraulic properties around fault zones and provide fast flow paths through hydrologic units that are otherwise not prone to fracture flow. Even nonwelded units, such as the Pah Canyon and Calico Hills tuffs, may allow groundwater flow in fractured zones adjacent to faults. The extent of rock property modification due to faulting (i.e., fracture zones related to faulting) generally correlates with the amount of movement on the fault (i.e., faults with larger displacements have larger fractured zones).

2.1.2 YMP Previous Work: Volcanism

In this section discussion of previous YMP geologic study and site characterization focuses on summarizing the evaluations of conceptual models and data for volcanism from the PVHA. A discussion of the contribution of past PA analysis of volcanism through the TSPA-VA is also contained in this section.

2.1.2.1 Volcanism Studies for Site Characterization

Assessment of the volcanic hazard at Yucca Mountain evaluated late Tertiary and Quaternary igneous activity. Volcanism studies have been ongoing for the past two decades as part of the site characterization to determine the ages and character of past volcanic episodes in the Yucca Mountain region and to understand the tectonic setting with which volcanic activity is associated. These investigations included:

- Geologic mapping of Miocene and post-Miocene basalt centers
- Geochronology analyses: isotopic age determinations to date post-Miocene basalts of the Yucca Mountain region

- Geochemistry and petrology studies: major element, trace element, isotopic, and mineral chemistry data obtained for all basalt units of the post-Miocene basalts
- Evaluations of the eruptive history of Yucca Mountain region Quaternary basaltic centers
- Geophysical evaluations related to Yucca Mountain region basaltic volcanism
- Analysis of structural controls on basaltic volcanism
- Analog studies of eruptive centers.

The results of these studies are summarized in the *Yucca Mountain Site Description* (CRWMS M&O 2000ab, Section 3.9).

2.1.2.2 Probabilistic Volcanic Hazard Analysis

Founded upon this extensive base of data, analyses, and interpretation, a PVHA (CRWMS M&O 1996) was conducted to determine the probability of igneous activity intersecting the potential repository. To ensure appropriate quantification of scientific uncertainty in the hazard analysis, the DOE identified ten experts to evaluate data, volcanic processes, and features. The product of the PVHA was a quantitative assessment of the probability of a basaltic dike intersecting the potential repository and the uncertainty associated with the assessment. The result of this expert elicitation is volcanic hazard that reflects a diversity and range of alternative scientific interpretations.

The major procedural steps in the PVHA were: (1) selecting the expert panel members, (2) identifying the technical issues, (3) eliciting the experts' evaluations, and (4) performing probabalistic calculations. From more than 70 nominees, 10 individuals were selected to evaluate volcanic processes and models and develop input interpretations. The panel was carefully balanced with respect to technical expertise (physical volcanology, geochemistry, and geophysics) and institutional/organizational affiliation (CRWMS M&O 1996, Table 1-2).

At the core of the PVHA elicitation were four workshops. The primary objective of the workshops was to ensure the experts' understanding of the issues, volcanic processes, alternative volcanic models, volcanic features, and the data. The first three workshops focused on the data, volcanic processes and models, and interpretations relevant to the PVHA. The workshops included presentations of data and interpretations by technical specialists from Los Alamos National Laboratory, the U.S. Geological Survey, the University of Nevada, Las Vegas, the Center for Nuclear Waste Regulatory Analysis, and some PVHA project experts. During the fourth workshop, the experts reviewed the preliminary evaluations developed by the panel members, after which the individual evaluations were revised based on feedback received. Two field trips held during the course of the PVHA provided the opportunity for the panel members to observe volcanic features and relationships pertaining to eruptive style and the distribution and timing of volcanic activity in the Yucca Mountain region.

The experts developed temporal and spatial models of volcanic activity for hazard calculation. Temporal models describe the frequency of occurrence of volcanic activity and include homogeneous and nonhomogeneous (time varying) models. Homogeneous Poisson temporal models assume a uniform rate of volcanism based on the number of volcanic events that occurred during various periods in the past. Nonhomogeneous temporal models were used to describe volcanic clustering in time or to describe the possible waning or waxing of volcanic activity in the region. Most of the experts considered the homogenous temporal model to be appropriate for assessing the hazard, typically including uncertainty in the appropriate time period. The rest used both homogenous and nonhomogenous temporal models as weighted alternatives.

In order to capture the uncertainty in the location of future volcanic events in the Yucca Mountain region, the PVHA experts used a variety of spatial models. Three types of models were used. Volcanic *source zones* represent regions in which the future occurrence of volcanoes is spatially homogeneous within the zone and may vary from zone to zone. These source zones are defined using several criteria and observations: the spatial distribution of observed basaltic volcanic centers (especially post-5 million-year-old centers), structurally controlled regions, regions defined based on geochemical affinities, topography, and tectonic provinces. *Parametric spatial models* represent the spatial distribution of future volcanic events in a volcanic field that follow a given distribution. The distribution used was a bivariate Gaussian distribution. *Nonparametric* estimation techniques define the spatial distribution of future events by "smoothing" the locations of known events using a smoothing function. The PVHA experts included alternative source zone configurations, parametric field parameters, and smoothing parameters in their models to reflect the diversity and range of scientific interpretations.

Formal elicitation followed the third workshop. The process consisted of a two-day individual interview with each expert. To provide consistency the same interview team was used for all elicitations. Following the elicitation interview each expert was provided with a draft written summary of their elicitation that was prepared by the interview team. The experts reviewed their initial assessments and summary and clarified and/or revised as appropriate. To promote a full understanding of each individual's evaluations, as well as a full understanding of the important issues in the hazard assessment, the draft assessments were presented and discussed at the fourth workshop. Following this workshop each expert received detailed feedback regarding the sensitivity of his results to various interpretations and finalized his interpretations (CRWMS M&O 1996, Appendix E). These finalized interpretations were used to calculate the volcanic hazard.

The product of the PVHA was a quantitative assessment of the probability of a basaltic dike intersecting the potential repository (CRWMS M&O 1996, Figure 4-32). Specifically, the hazard is a probability distribution of the annual frequency of intersection of a basaltic dike with the repository footprint.

A probability distribution of the annual frequency of intersection of the repository footprint by a dike that typically spanned approximately 2 orders of magnitude was computed for each of the ten experts (CRWMS M&O 1996, Figure 4-31). From these individual probability distributions an aggregate probability distribution was computed that reflected the uncertainty across the entire expert panel (CRWMS M&O 1996, Figure 4-32). The distributions of individual experts were combined using equal weights. The mean value of the aggregate probability distribution was 1.5×10^{-8} dike intersections per year with a 90 percent confidence interval of 5.4×10^{-10} to 4.9×10^{-8} (CRWMS M&O 1996, p. 4-10). These values have been updated for the current repository footprint, EDA II Design B (CRWMS M&O 1999a) and the SRSL design (i.e., the 70,000-metric tons of uranium (MTU) no backfill layout) (CRWMS M&O 2000z), as discussed in Sections 3.1.1 and 3.1.4 of this Disruptive Events PMR. The composite distribution for intersection frequency spanned about three orders of magnitude. The range in the mean frequencies of intersection for the individual experts' interpretations spanned about one order of magnitude (CRWMS M&O 1996, Figure 4-32). The variance for frequency of intersection defined by the composite distribution was disaggregated to identify the contributions from each of the sources of uncertainty, including variability between the experts' interpretations (CRWMS M&O 1996, Figure 4-33). The majority of the uncertainty in characterizing a hazard arose from uncertainty in an individual expert's evaluations of volcanic processes and model interpretations of the hazard, rather than differences in interpretations between the experts (CRWMS M&O 1996, p. 4-10, Figure 4-33). The probability distribution arrived at by the PVHA accounted for uncertainty in the number of undetected events (buried volcanic vents or intrusive activity that never reached the surface). The undetected event frequency ranged from 1 to 5 times that of observed events, with most estimates in the range of 1.1 to 1.5 (CRWMS M&O 1996, Figure 3-62).

The PVHA results indicated that the uncertainty in estimating the event rate was the largest component of intraexpert uncertainty (CRWMS M&O 1996, p. 4-10, Figure 4-33). The next largest uncertainty was in the appropriate spatial model. Other important spatial uncertainties included the spatial smoothing distance, Gaussian field parameters, zonation models, and event lengths. The temporal issues of importance included the time period of interest, event counts at a particular center, and the frequency of hidden events (CRWMS M&O 1996, Figure 4-33).

2.1.2.3 TSPA-VA Analysis of Volcanism

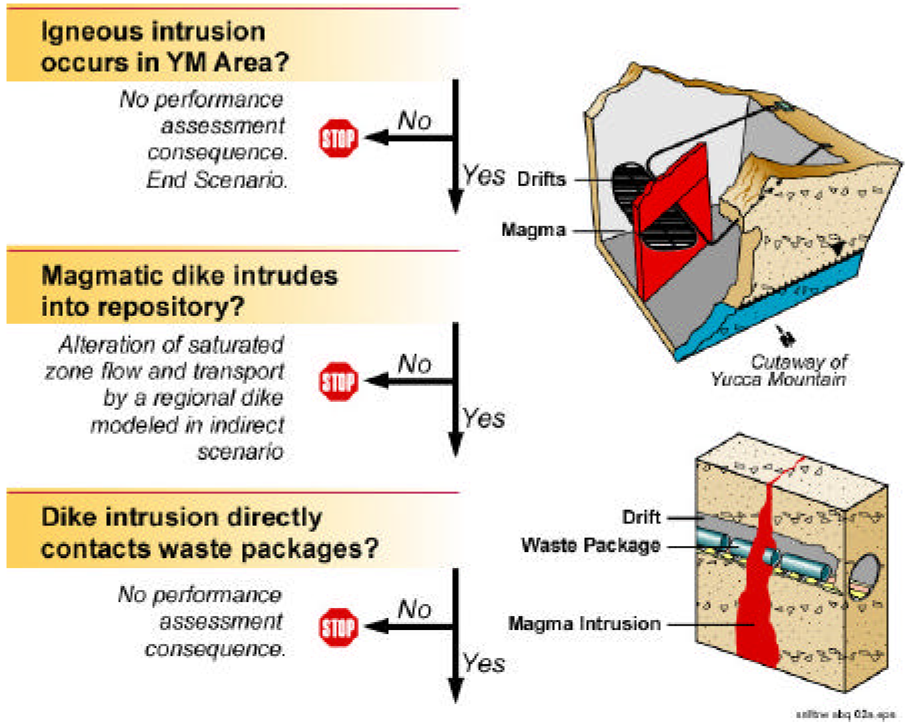
The PVHA, which focused on the volcanic hazard at the site, provided significant input to assessment of volcanic risk for the TSPA-VA analysis (DOE 1998a, Section 4.4). Details of the analysis of volcanic disruptive events scenarios were described in Chapter 10, "Disruptive Events," of the *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document* (CRWMS M&O 1998b, Section 10.4).

The disruptive events analyses for volcanism in TSPA-VA were constructed based on FEPs scenarios developed from the immediately preceding TSPAs (see list of previous TSPAs in Section 2.0). PAs previous to TSPA-VA used generalized event trees for constructing disruptive scenarios that lead to understanding the processes that could contribute to increased radionuclide releases from disruptive events. In addition to analyzing FEPs that were determined to be important from previous TSPAs, disruptive events volcanism analyses for TSPA-VA were prepared with the view of addressing the two subissues and acceptance criteria of the NRC's IRSR for Igneous Activity, Rev. 1 (NRC 1998e, Section 5). The volcanism analysis for TSPA-VA used probability information and descriptions of the nature of volcanic processes and events from the PVHA expert elicitation (CRWMS M&O 1996).

Three igneous activity effects scenarios were analyzed for TSPA-VA: (1) direct release, (2) enhanced source term, and (3) indirect effects. Two of these scenarios are taken forward for analysis in TSPA-SR (1 and 2); the third was screened out from further consideration. Screening arguments for excluding indirect effects (i.e., hydrologic response) from further analysis are contained in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h, FEP 1.2.10.02.00). The disruptive events FEPs AMR is summarized in Section 3.1.6 of this PMR, and a brief description of the FEP 1.2.10.02.00 screening argument is presented. The event tree method was used in TSPA-VA to determine potential consequences of igneous activity from whether a rising basaltic dike intersected emplacement drifts to the possibility of formation of a surface cinder cone and a contaminated ash plume. The TSPA-VA consequence scenario analysis process as understood at the time of TSPA-VA is captured in Figures 2-3 through 2-7.

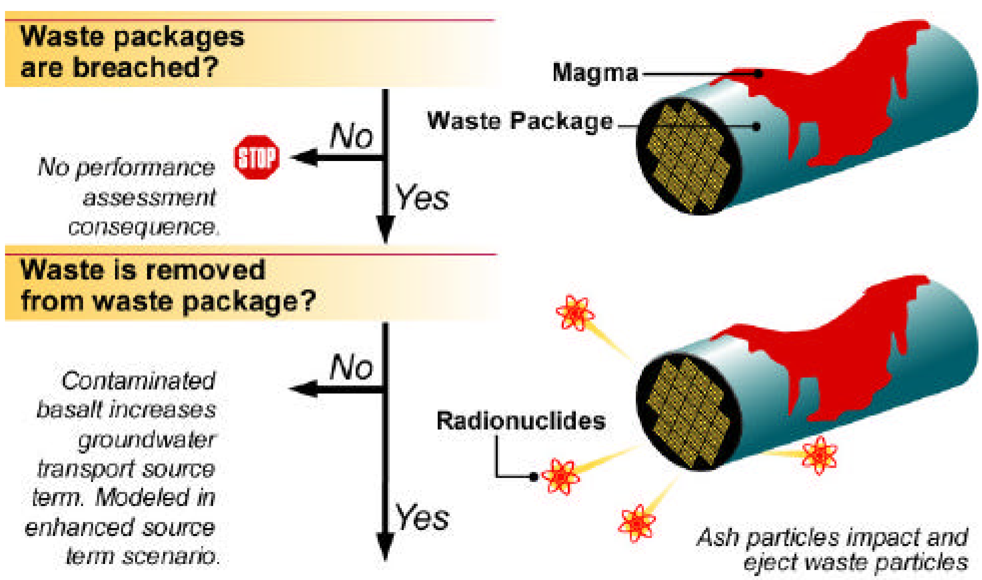
The event tree in Figure 2-3 depicts alternative consequences and decision points of a basaltic dike intersecting the potential repository and possibly contacting WPs. This represents the intrusive phase of volcanism that is common to both eruptive and intrusive events. The TSPA-VA analysis looked at consequences of both magma and ash particles contacting WPs, and the event tree for pyroclasts contacting WPs and waste is represented in Figure 2-4. WP breach was assumed to be by contact from pyroclasts (not by melting). Figure 2-5 is the event tree for waste entrainment in a volcanic ash cloud during an eruptive event. An event tree for release of waste from WPs engulfed in magma, but not entrained during an eruptive event, is depicted in Figure 2-6. This scenario analysis was called enhanced source term and analyzed release of waste into groundwater that entered WPs encased in cooled basalt years after the packages were compromised. The last TSPA-VA event tree, Figure 2-7, depicts the indirect effects scenario that was excluded from further analysis after TSPA-VA. This scenario represents a dike emplaced in the SZ having a significant effect on groundwater flow. TSPA-VA sensitivity studies (and subsequent disruptive events FEPs screening arguments) provided the basis for concluding that there would be no significant effect on dose from this scenario.

The direct release scenario (renamed as the volcanic eruption release for TSPA-SR) for TSPA-VA was one in which a volcanic eruption dispersed contaminated ash on the ground 20 km from the potential repository site. The processes included in the direct release scenario for the TSPA-VA are depicted in Figures 2-3, 2-4, and 2-5. The enhanced source term scenario (renamed igneous intrusion groundwater release for TSPA-SR) was liquid magma intersecting the repository drifts and engulfing WPs, compromising their integrity and leaving the contents exposed in the basaltic rock that formed from the cooled magma. The contents were then assumed to be available for transport in encroaching groundwater using the UZ and SZ flow TSPA models. Figures 2-3 and 2-4 were combined to support analysis of this scenario for TSPA-VA. The indirect igneous effects scenario was for the possible effects on groundwater flow in the SZ from dike emplacement assuming two possibilities, that the dike was either more or less permeable than the country rock it intruded. Figure 2-7 supported analysis of this scenario for TSPA-VA and, as previously mentioned, this scenario was not analyzed for TSPA-SR. Further details of the assumptions and methods used in the TSPA-VA analysis can be found in Section 3.1.5, where the disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) is discussed.



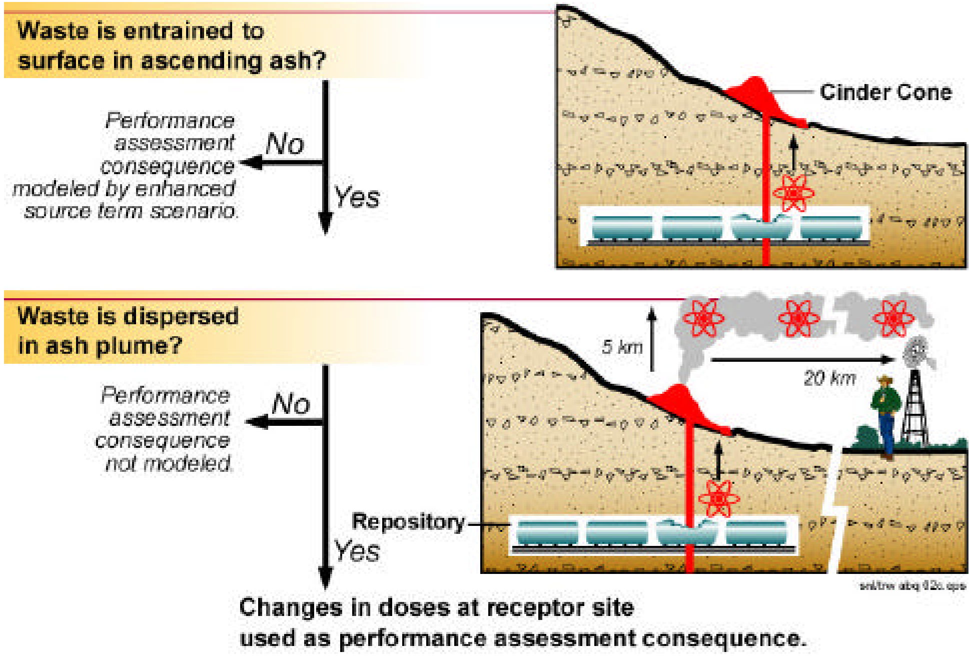
Source: DOE 1998a, Figure 4-41a

Figure 2-3. TSPA-VA Event Tree Depicting Alternative Consequences and Decision Points for a Dike Intersecting the Potential Repository



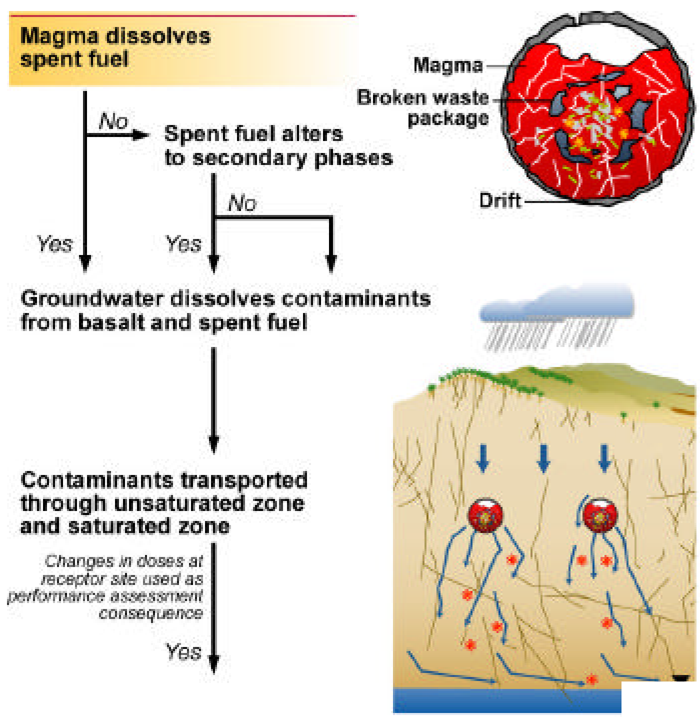
Source: DOE 1998a, Figure 4-41b

Figure 2-4. TSPA-VA Event Tree Depicting Alternative Consequences and Decision Points for Pyroclasts Contacting Waste Packages and Waste



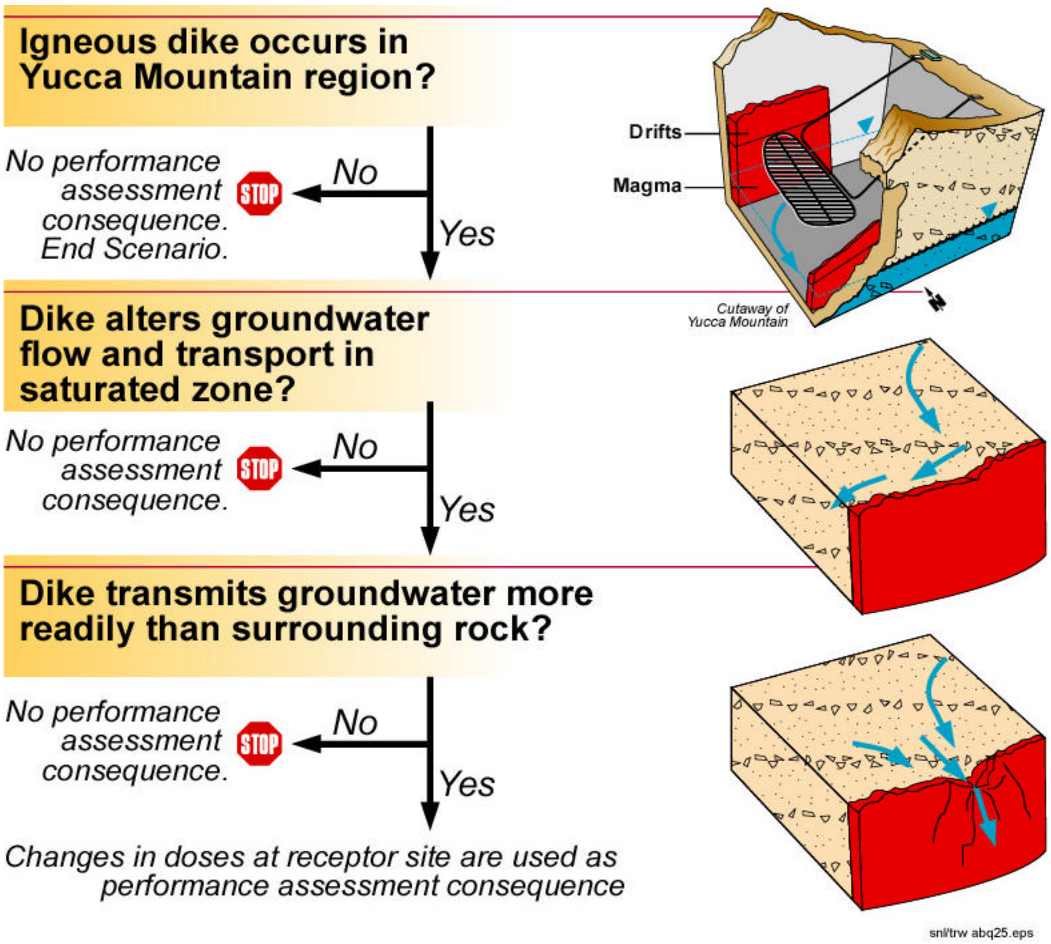
Source: DOE 1998a, Figure 4-41c

Figure 2-5. TSPA-VA Event Tree Depicting Alternative Consequences and Decision Points for a Volcanic Eruption Entraining Waste in an Ash Cloud after Intersecting the Potential Repository



Source: DOE 1998a, Figure 4-42

Figure 2-6. TSPA-VA Event Tree Depicting Alternative Consequences and Decision Points for a Release into Groundwater of Waste Picked Up from Waste Packages Engulfed in Magma That Subsequently Cooled



Source: DOE 1998a, Figure 4-43

Figure 2-7. TSPA-VA Event Tree Depicting Alternative Consequences and Decision Points for Examining the Effects of a Dike Emplaced in the Saturated Zone

2.1.3 YMP Previous Work: Seismicity and Structural Deformation

Comprehensive geologic and geophysical studies have been conducted to assess the seismic hazard at Yucca Mountain. The previous studies included: (1) ongoing site characterization activities that establish the site geologic framework (see CRWMS M&O 2000ab), (2) the seismic topical reports (YMP 1997a, 1997b; CRWMS M&O 1999h) that establish the methodology to be followed in assessing seismic hazard and preclosure design inputs, and (3) the PSHA that establishes the seismic hazard (Wong and Stepp 1998).

Scientific investigations and evaluation conducted over the past twenty years provide the basis for assessment of seismic hazards at Yucca Mountain (CRWMS M&O 2000c, Section 6.1.2). Building upon earlier investigations of the NTS region, studies of the Yucca Mountain site have included:

- Evaluations of faults within about 100 km for evidence of Quaternary activity
- Detailed paleoseismic fault-trenching studies of active faults near Yucca Mountain to determine the history and characteristics of past earthquakes

- Monitoring of contemporary seismicity
- Compilation of a catalog of historical and instrumentally recorded earthquakes in the Yucca Mountain region
- Development of ground motion attenuation relationships for extensional tectonic regimes, which includes the Yucca Mountain region
- Investigation of local site attenuation characteristics
- Numerical modeling of ground motion from scenario earthquakes
- Evaluation of the tectonic stresses from hydrofracture measurements and earthquake focal mechanisms
- Collection and analysis of geophysical data to assess tectonic models and identify subsurface faults
- Collection and analysis of geodetic data to measure ongoing crustal deformation.

This extensive database, in addition to the numerous studies performed by non-YMP scientists and the already existing literature and information, forms the basis for the Yucca Mountain PSHA (Wong and Stepp 1998).

2.1.3.1 Seismic Topical Reports

Two seismic topical reports have been prepared, and a third is in preparation, that together document the basis for seismic design of the potential repository. The seismic hazard results were developed principally for preclosure analyses; however, they also provide the basis for the postclosure PA analyses that are the focus of this PMR. Two of these reports have been presented to the NRC for its review and comment. The third report is currently being prepared for completion after TSPA-SR. A PSHA was conducted based on the methodology developed in Topical Report 1. Both Topical Report 2 and Topical Report 3 document the preclosure seismic design methodology and results.

Seismic Topical Report 1, *Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain* (YMP 1997a), contains a description of the DOE methodology for probabilistic assessment of vibratory ground motion and fault displacement hazards. The methodology involves a series of workshops structured so that multiple experts can interact to evaluate hypotheses and models using the geological, geophysical, and seismological data sets from the Yucca Mountain area. The methodology requires that the experts specifically evaluate all hypotheses and models that have credible support in the data. The product of the methodology is multiple interpretations by the experts of seismic sources, source properties, and evaluations of ground motion, all of which include specific expressions of uncertainty. Comprehensive and consistent consideration of data and documentation of all interpretations is required by the methodology. This topical report guided the process followed for the PSHA expert elicitation.

Seismic Topical Report 2, *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain* (YMP 1997b), contains a description of the design methodology and criteria that the DOE intends to implement to provide reasonable assurance that vibratory ground motion and fault displacements will not compromise the preclosure function of repository systems important to safety. The report establishes hazard probability levels that are appropriate for determining design basis vibratory ground motions and design basis fault displacements. Acceptance criteria for both surface and underground facilities are provided for vibratory ground motion and fault displacement design. The report also provides criteria for fault avoidance and seismic design considerations for WPs.

Seismic Topical Report 3, *Preclosure Seismic Design Basis for a Geologic Repository at Yucca Mountain* (described in its development plan CRWMS M&O 1999h), the last of the methodology reports, will contain a description of the development of seismic design basis inputs for appropriate frequencies of occurrence as defined in Topical Report 2. The results of the PSHA will be summarized, including the characterizations of seismic sources, fault displacement, and ground motion attenuation developed by the two panels of experts (described in the discussion of the PSHA that follows). Design basis earthquake ground motions will be defined for three specific sites that represent the range of locations and conditions where repository facilities would be located.

Though the primary topic of Seismic Topical Report 3 is preclosure seismic design, it will also provide a roadmap and discussion of the overall approach to incorporating ground motion and fault displacement hazards in postclosure analyses. The topical report will provide a roadmap to relevant AMRs and PMRs and other YMP documentation that contain hazard results and other details to be used as input to postclosure performance assessment. The topical report will state why this information is relevant to performance assessment and how it will be used.

2.1.3.2 Probabilistic Seismic Hazard Analysis

A PSHA that assessed both ground motion and fault displacement hazards was conducted for the potential repository at Yucca Mountain. The PSHA combines seismic source zones and their associated earthquake recurrence with appropriate attenuation relationships to produce “hazard curves” in terms of level of ground motion and an associated probability of that ground motion being exceeded annually. The study, *Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada* (Wong and Stepp 1998), was a four-year multidisciplinary project that was based on expert elicitation. The disruptive events AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c) contains more detail and roadmapping to sections of the PSHA and is summarized in Section 3.2.1.2 of this PMR.

Many scientists and engineers participated in and contributed to the PSHA (Wong and Stepp 1998, Appendices A, C, and D). These individuals were associated with universities or government agencies or were experts from industry. Six teams of three experts each, who together formed a composite expertise in the seismicity, tectonics, and geology of the Yucca Mountain region, made seismic source characterizations. Seven individual experts made the ground motion assessments. Many other researchers participated in workshops and field trips devoted to the discussion of available data and possible interpretations of these data. The experts' interpretations specifically incorporated uncertainties related to the data and to resolving different hypotheses and models. The uncertainties that were factored into the analyses reflected the range of views of the many individuals that contributed to the hazard assessment. The experience level and diversity of PSHA participants in a wide variety of tectonic environments supported an appropriate representation of uncertainty through the composite distribution of views represented by diverse participants from the scientific community.

The objectives of the PSHA analyses were to support assessments of the potential repository's long-term performance and seismic design criteria development for facility design (Wong and Stepp 1998, Section 1.1). Quantitative hazard results were developed in the form of annual exceedance probabilities for various levels of fault displacement at selected locations and vibratory ground motion at a hypothetical rock outcrop at the ground surface. Both the preclosure and postclosure performance periods of the repository were addressed in the PSHA study. Three primary activities of the study were:

- Identifying, evaluating, and characterizing the seismic sources that contribute to the fault displacement and vibratory ground motion hazard at Yucca Mountain

- Evaluating and characterizing the vibratory ground motion attenuation including earthquake source, wave propagation path, and rock site effects

- Conducting a probabilistic hazard analysis for both fault displacement and vibratory ground motion.

The uncertainty assessments for the PSHA were performed and expressed using logic tree methodology (Wong and Stepp 1998, Section 4.1.1). This involved setting out the sequences of assessments that must be made to perform the analysis and then addressing the uncertainties in each assessment sequentially. Relative weights were assigned to alternative models or interpretations that reflected the degree of support that the interpretation or parameter value had in the data. Weighted alternative parameter values and estimated continuous distributions were used.

There are three principal components of seismic source characterization: source location and geometry, maximum earthquake magnitude, and earthquake recurrence. A discussion of each of the components and the uncertainties that can be addressed for each follows.

2.1.3.2.1 PSHA Summary: Seismic Source Location and Geometry

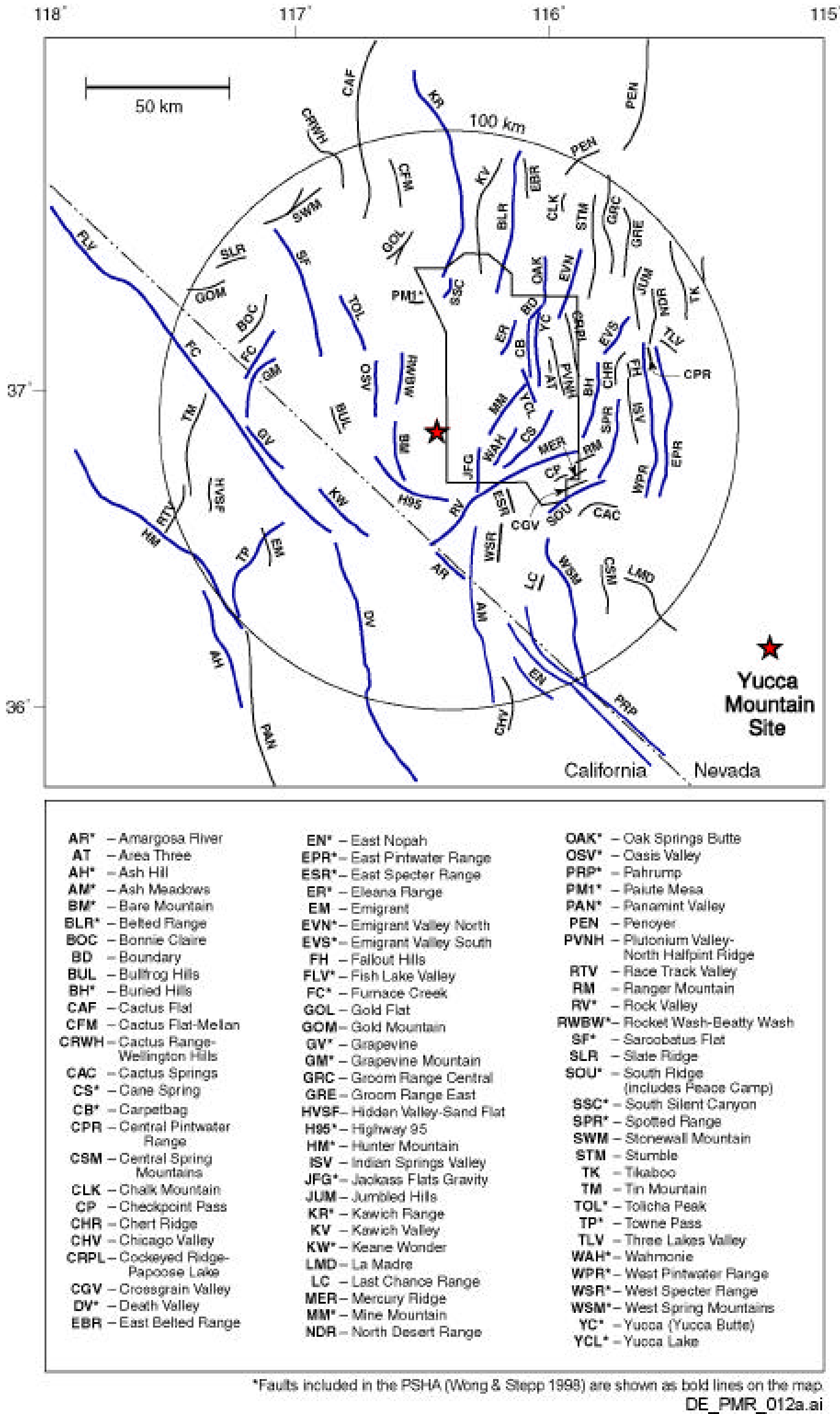
A seismic source is defined as a region of the earth's crust that has relatively uniform seismicity characteristics, is distinct from those of neighboring sources, and can be used in approximating the locations of future earthquakes. It is a construct developed for seismic hazard analysis as a means of approximating the locations of earthquake occurrences. Seismic sources can be categorized into two basic source types: fault sources and areal sources (Wong and Stepp 1998, Section 4.1.2). Fault sources are represented as lines or planes and represent the occurrence of earthquakes along a known or suspected fault trace. Areal sources represent areas of distributed seismicity that are not apparently associated with specific, known faults. Areal sources can be divided into three types: a source whose boundary encloses a concentrated zone of seismicity, a source defined by regional seismotectonic characteristics, and a regional background source (typically applying to a larger region than is defined by the other area sources). The boundaries of areal sources delineate areas that have relatively uniform seismic potential in terms of earthquake occurrence and maximum earthquake magnitude. The basic characteristics that must be defined for all source types are the same (i.e., location, maximum magnitude, and recurrence); however, the particular parameters and data sets that are used to define these characteristics may be quite different.

The seismic source study includes analysis of seismic moment, which is a measure of the strength of the earthquake. Magnitude, also a measure of earthquake size, is determined by taking the common logarithm (base 10) of the largest ground motion recorded by a seismograph and applying a correction for the distance to the earthquake. Several scales have been defined, but the most commonly used are: (1) local magnitude (M_L), commonly referred to as "Richter Magnitude," (2) surface-wave magnitude (M_s), and (3) body-wave magnitude (m_b). All of these scales have limited range and applicability and do not satisfactorily measure the size of the largest earthquakes. In contrast, the moment magnitude (M_w) scale, based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes but is more difficult to compute than the other types.

The seismic source expert teams considered two types of fault sources: regional faults and local faults. Regional faults were defined by most teams as Quaternary faults within 100 km of Yucca Mountain, but outside the local vicinity of the site, that were judged to be capable of generating earthquakes of M_w 5 and greater. Local faults were defined as being located within about 15 km of Yucca Mountain. Paleoseismic data from numerous references (see Wong and Stepp 1998, Appendix B) were used by all the teams to identify and characterize fault sources, some of which were regional. Faults were considered, but not judged relevant to the hazard analysis, if they had short lengths or no significant Quaternary displacement (Wong and Stepp 1998, p. 4-49).

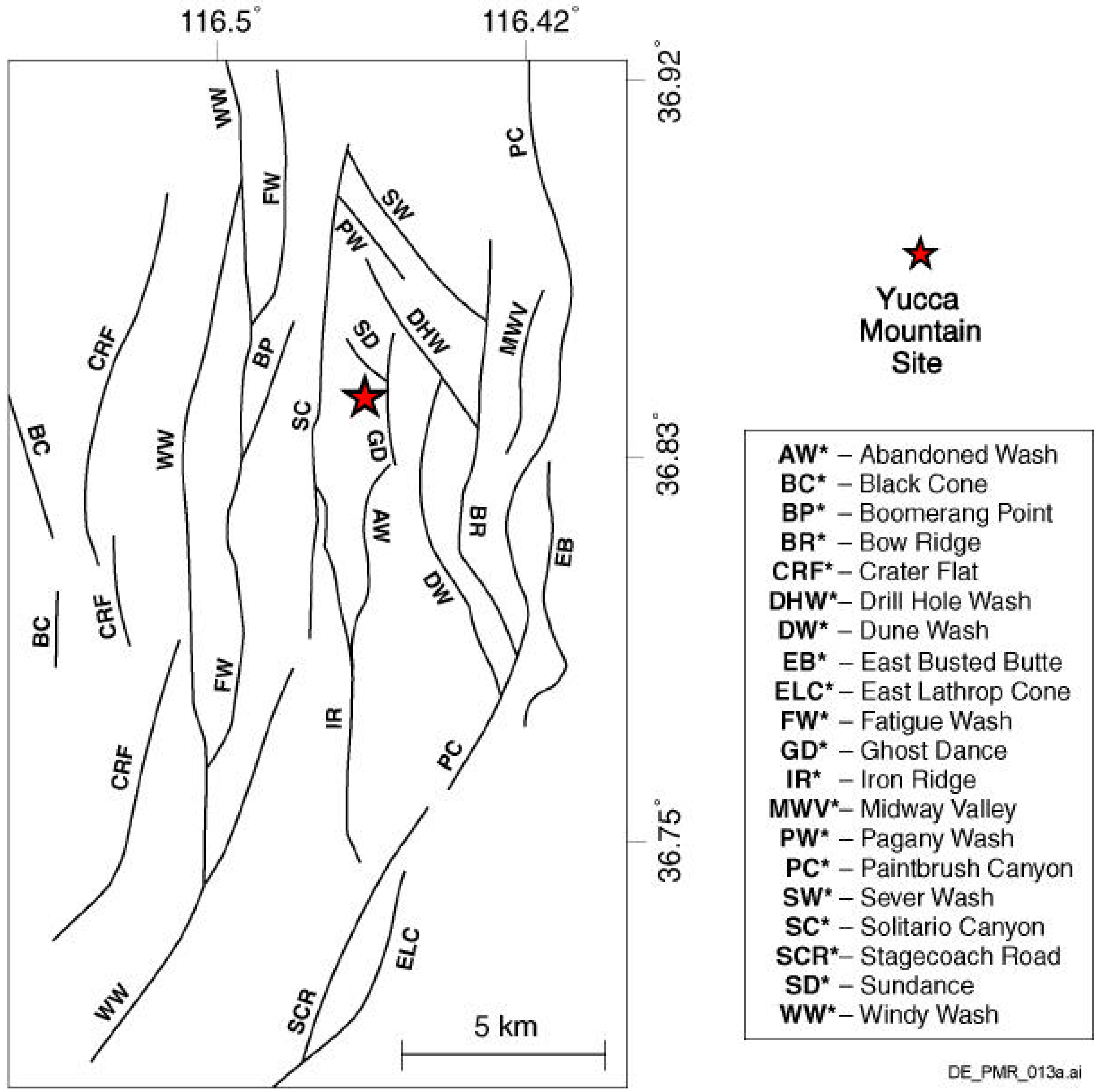
2.1.3.2.2 PSHA Summary: Regional Faults, Local Faults, Areal Source Zones, and Volcanic Sources

The number of regional faults considered by the expert teams ranged from 11 to as many as 36. This reflected, in part, the judgments of the teams regarding the activity of various faults as well as the decision by some teams to also include potentially active faults. Some teams also considered areal source zones as adequately representing regional faults. All the teams modeled the regional faults as simple, planar faults to maximum seismogenic depth with generalized dips depending on the style of faulting (preferred values of 90° for strike-slip faults and 60° or 65° for normal-slip faults). Alternative fault lengths for most of the faults were included by all the teams to express uncertainty in their mapped lengths. Of the regional faults, the most significant were the Furnace Creek and Death Valley faults, despite their relatively great distances from the Yucca Mountain site ($\geq$ 50 km), because of their high slip rates (2.5 to 8 mm/yr.) and potential to generate maximum magnitude (M_{max}) earthquakes of about M_w 7.5. Figure 2-8 shows the known or suspected Quaternary faults and potentially significant local faults within 100 km of Yucca Mountain; local faults in the immediate vicinity of Yucca Mountain are shown in Figure 2-9.



Source: Modified from CRWMS M&O 2000c, Figure 6

Figure 2-8. Known or Suspected Quaternary Faults and Potentially Significant Local Faults within 100 km of Yucca Mountain



Source: CRWMS M&O 2000c, Figure 6

NOTE: This map is a blow-up of the Yucca Mountain Site shown in Figure 2-8.

Figure 2-9. Known or Suspected Quaternary Faults and Potentially Significant Local Faults in the Vicinity of the Yucca Mountain Site

Varying behavioral and structural models were employed by the expert teams to represent the full range of possible rupture patterns and fault interactions in the characterization of local faults. Most teams preferred a planar fault model. Some of the faults could have been interconnected, with linkages along strike or coalescence down-dip. Some type of simultaneous rupture of multiple faults was included in all models. In general, preferred models for multiple fault rupture included two to four coalescing fault systems. Several teams used detachment models to constrain the extent and geometry of local fault sources. A seismogenic detachment fault was considered, but not strongly favored, as a source of large earthquakes by the teams. The possibility that right-lateral shear is accommodated in the Yucca Mountain region by a buried strike-slip fault was considered by all expert teams. Most teams included some variation of a regional buried strike-slip fault source, though with low probability.

Areal source zones were defined by the expert teams to account for background earthquakes that could occur on potential buried faults or faults not explicitly included in their model. Some teams included alternative areal zone models in their characterization within a 100 km radius of the Yucca Mountain site. The teams also defined areal zones that extended beyond 100 km from the Yucca Mountain site to completely express uncertainty in the seismic source interpretations. Several teams defined a site area, or zone, solely for assigning a lower M_{max} to the area where more detailed investigations had been conducted and the inventory of fault sources was more complete.

Seismicity related to volcanic processes, specifically to basaltic volcanoes and dike-injection, was considered by all teams, but explicitly modeled as distinct source zones by only two expert teams (Wong and Stepp 1998, Table 4-1). Volcanic-related earthquakes were not modeled as a separate seismic source by the other four teams because the low magnitude and frequency of volcanic-related seismicity was assumed to be accounted for by earthquakes in the areal zones.

2.1.3.2.3 PSHA Summary: Maximum Earthquake Magnitudes

M_{max} earthquakes were defined for each seismic source by each team to represent the largest earthquake that the source is capable of generating, regardless of how frequently it occurred (Wong and Stepp 1998, p. 4-49). As discussed in Section 2.1.3.2.2, numerous seismic sources were characterized, and each of these different sources has been assigned a maximum magnitude. The maximum earthquakes from all sources were incorporated in the vibratory ground motion hazard assessment (described in Section 2.1.3.2.5). There are two basic approaches to assessing maximum magnitudes for seismic sources: constraints provided by estimates of maximum dimensions of fault rupture and constraints provided by historical seismicity. As is common in most parts of the world, the historical seismicity record is too short to have observed and recorded with certainty the maximum earthquakes on seismic sources in the Yucca Mountain region. Hence, estimates of fault rupture dimensions are the principal means of estimating maximum magnitudes. Uncertainties in estimating the physical dimensions of the maximum rupture on the faults were explicitly incorporated into the analysis.

The approach used to evaluate the M_{max} for faults was to estimate the maximum dimensions of rupture and then compare those dimensions in empirical relationships between rupture dimensions and earthquake magnitude. The types of empirical relationships available were: magnitude versus rupture length, magnitude versus rupture area, magnitude versus maximum surface displacement, and magnitude versus average surface displacement.

For areal sources the M_{max} for the zone was based primarily on consideration of the historical seismicity record. The M_{max} could also have been selected as representing the largest earthquake determined to occur on any of the faults within the areal zone. If an areal zone was used to model the occurrence of earthquakes on unknown faults, the M_{max} for the zone was determined by the largest fault mapped within the zone or the largest earthquake that was not associated with surface faulting. This ensured that any unknown or unidentified faults were accounted for.

2.1.3.2.4 PSHA Summary: Earthquake Recurrence

Earthquake recurrence relationships express the rate or annual frequency of earthquakes occurring for a single seismic source. Seismic sources generate a range of earthquake magnitudes up to the maximum magnitude. A magnitude-distribution model defines the relative number of earthquakes having particular magnitudes. Methods for developing recurrence relationships are usually different for fault sources than for areal sources. Recurrence rates for fault sources are usually estimated from geologic data, while for areal sources historical seismicity data are used.

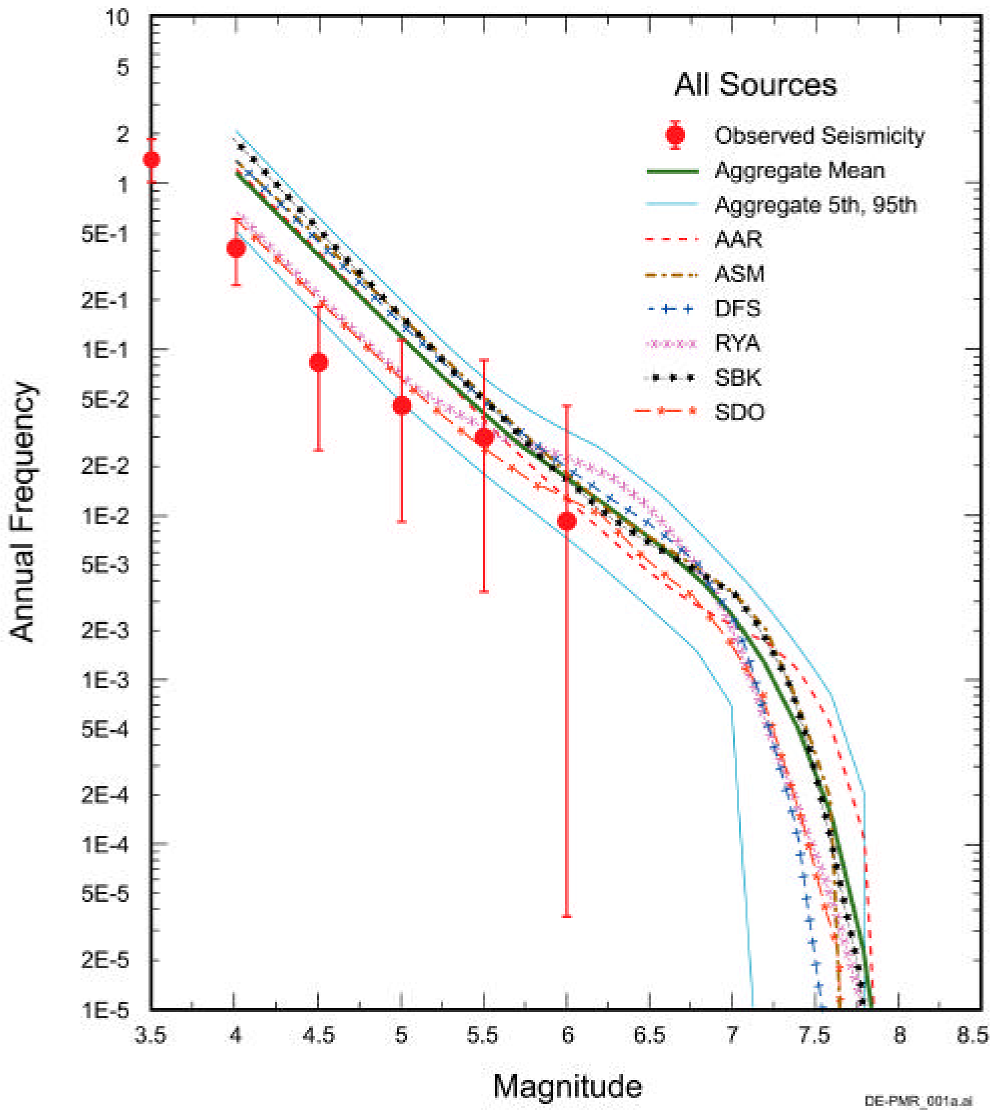
Two approaches were used to estimate the earthquake recurrence relationships for fault sources (Wong and Stepp 1998, Section 4.3.1.2). The first involved estimating the frequency of large-magnitude, surface-rupturing earthquakes on the fault either by dating of paleoearthquakes or by dividing an estimate of the fault slip rate by an estimate of the average slip per event. The second approach was to translate the estimated fault slip rate into a seismic moment rate and then partition the moment into earthquakes of various magnitudes according to the magnitude-distribution model used.

For areal sources, earthquake recurrence relationships were determined from the historical seismicity. The earthquake catalog for the region within a 300-km radius of the Yucca Mountain site was compiled from all available regional and national earthquake catalogues. All known NTS blasts were identified and removed. The catalog was analyzed to identify and remove dependent events (earthquakes that were aftershocks or foreshocks of larger earthquakes).

Figure 2-10 compares the combined distribution for earthquake recurrence from all seismic sources and the mean results for the six expert team characterizations. There is generally less than an order of magnitude range in uncertainty in the estimation of regional seismicity rates. At smaller magnitudes, the range reflects the differences in how the teams characterized the regional source zones. At larger magnitudes, the assessments from the individual teams lie within the uncertainty in the occurrence rates of earthquakes based on the historical record. Because the ground motion hazard, at least for high spectral frequency ground motions, is influenced largely by nearby seismic sources, the larger uncertainty in recurrence rates for the local sources has a significant effect on the uncertainty in the ground motion hazard.

2.1.3.2.5 PSHA Summary: Vibratory Ground Motion Hazard

The level of ground shaking, expressed as the amplitude of ground motions, is a function of three main elements: the seismic source, the source-to-site path, and the site conditions. The source conditions include the magnitude of the earthquake, style of faulting, and geometry of the coseismic fault rupture. The second element is the travel path of seismic waves from the source of the earthquake to a particular site. The length of this path is important, because the amplitude of ground motions will decrease, or attenuate, with distance. The third element is the local site condition, or the effect of the uppermost several hundred meters of rock and soil and the surface topography. All three of these elements that control ground motions were explicitly addressed in the Yucca Mountain seismic hazard analysis. When the ground motion analysis is combined with the seismic source characteristics, a probabilistic representation of vibratory ground motion hazard is produced.



Source: Modified from CRWMS M&O 2000c, Figure 8

NOTE: Initials represent the last names of the members of PSHA teams (Wong and Stepp 1998).

AAR = Arabasz, Anderson, Ramelli
ASM = Ake, Slemmons, McCalpin
DFS = Doser, Fridrich, Swan
RYA = Rogers, Yount, Anderson
SBK = Smith, Bruhn, Knuepfer
SDO = Smith, dePolo, O'Leary

Figure 2-10. Combined Distribution for Earthquake Recurrence from All Seismic Sources and Mean Results for the Six PSHA Expert Team Characterizations

Vibratory ground motion hazard must be computed for use in designing repository facilities and in PAs of the potential repository during the postclosure period. Repository facilities would be located in the subsurface and on the surface at sites underlain both by tuff bedrock and by thick alluvium. Ground motions at each of these areas will be different because of the different site conditions. For the PSHA, ground motion hazard calculations were made for a hypothetical site termed Point A (see Figure 2-11). Point A was defined to have the characteristics of a rock outcrop located at the repository elevation. More explicitly, rock characteristics at the repository level are used for ground motion calculations; however, the calculation does not reflect the 300 m of overburden that exists above the repository. A point that had characteristics of a rock outcrop was defined because most empirical and numerical ground motion models have been developed to express ground motions at the surface of the earth. The ground motion experts developed ground motion models appropriate for the conditions at Point A, and the resulting hazard calculations apply to this point.

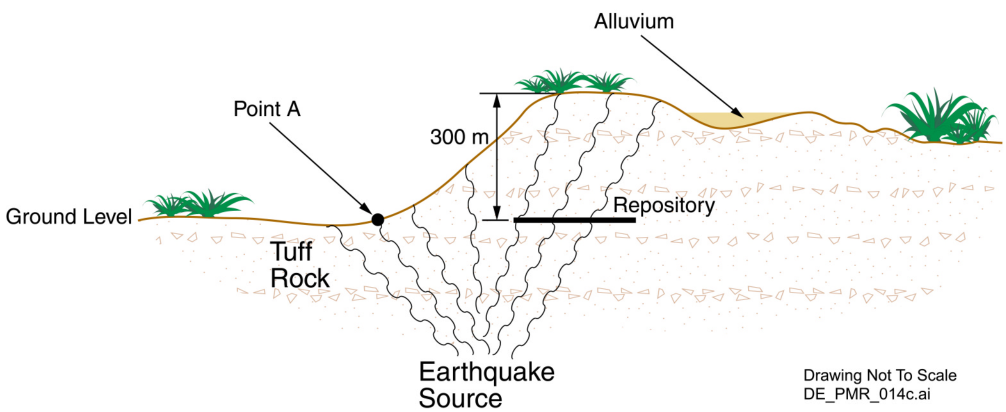
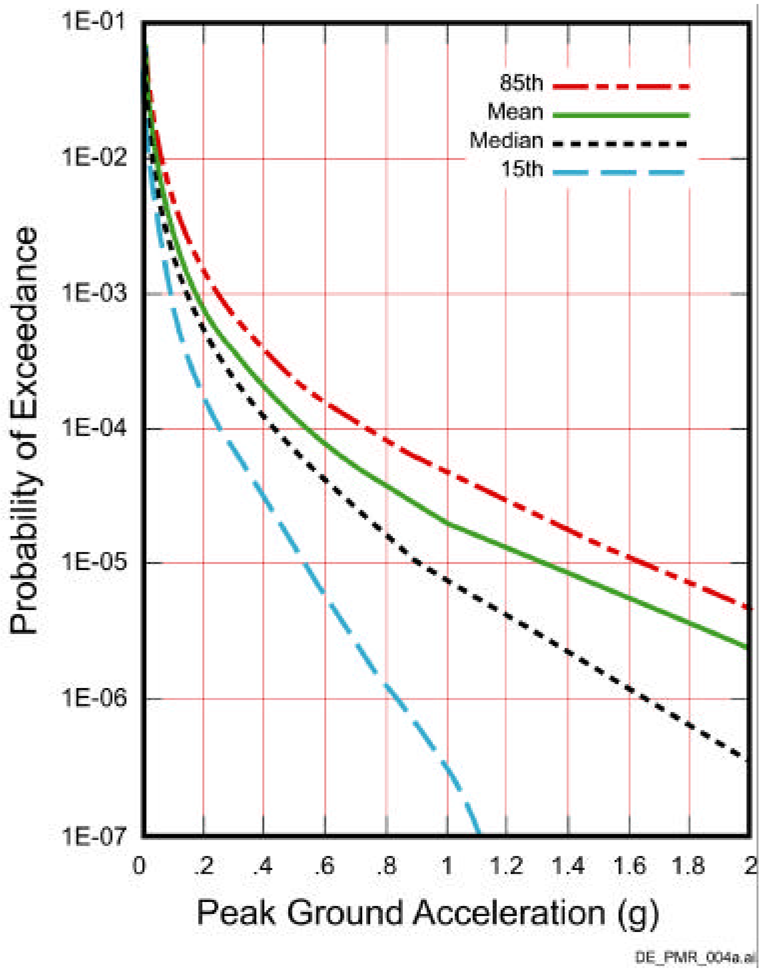


Figure 2-11. Reference Point for Ground Motion Calculations

The seven ground motion experts estimated median ground motion and uncertainties for a matrix of earthquake magnitudes, source-to-site distances and faulting styles (normal- and strike-slip), and for a suite of spectral frequencies. The probabilistic hazard for vibratory ground motion was calculated based on equally weighted inputs from the six seismic source expert teams and the seven ground motion experts. The probabilistic hazard was calculated for horizontal and vertical peak acceleration; spectral accelerations at frequencies of 0.3, 0.5, 1, 2, 5, 10, and 20 Hz; and peak velocity. It was expressed in terms of hazard curves (see Figure 2-12). The hazard was also expressed in terms of uniform hazard spectra (see Figure 2-13) (Wong and Stepp 1998, Section 7.3).

Disaggregation of the mean hazard or magnitude, distance, and ground motion variability for an annual exceedance probability of 10^{-4} shows that at 5 to 10 Hz (or other high frequencies) ground motions are dominated by earthquakes of smaller than M_w 6.5 occurring at distances of less than 15 km. Dominant events for low-frequency ground motions, such as at 1 to 2 Hz, display a bimodal distribution, including large nearby events and M_w 7 and larger earthquakes beyond distances of 50 km (see Figure 2-14). The latter contribution is due mainly to the relatively higher activity rates for the Death Valley and Furnace Creek faults.



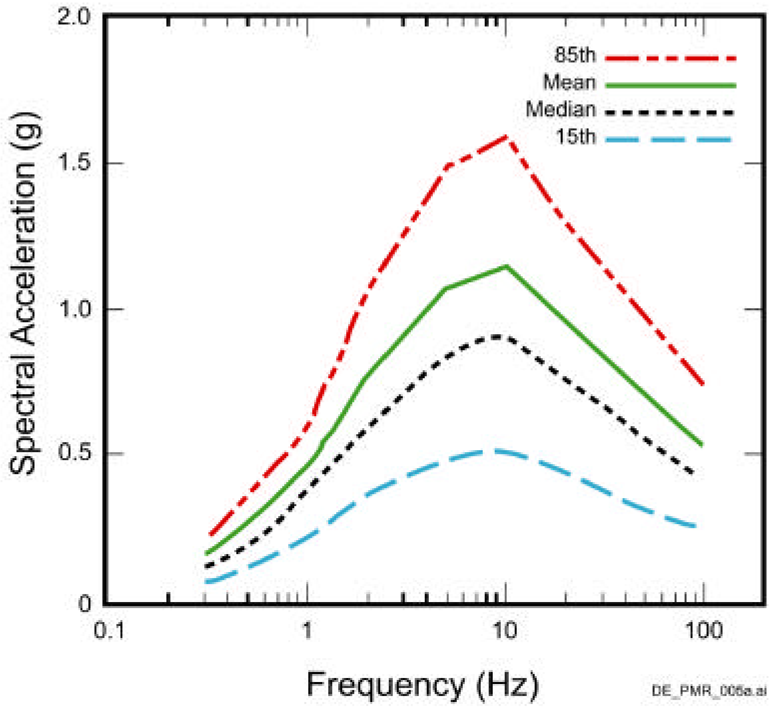
Source: Modified from CRWMS M&O 2000c, Figure 11a

NOTES: Probability of exceedance refers to annual probability; g = acceleration due to gravity, 9.8m/sec^2.

Figure 2-12. Integrated Seismic Hazard Results: Hazard Curves for Horizontal Peak Ground Accelerations

2.1.3.2.6 PSHA Summary: Fault Displacement Characterization

Fault displacement hazard is the hazard related to differential slip that occurs at the surface along a seismogenic fault or along secondary faults triggered by the seismogenic rupture. Several alternative approaches to characterizing fault displacement hazard assessment were developed by the experts (Wong and Stepp 1998, Section 4.3.2). The approaches were based primarily on empirical observations of faulting characteristics at Yucca Mountain and in the Basin and Range province during past earthquakes. The method for assessing probabilistic fault displacement hazard was similar to that for vibratory ground motion hazard. The hazard was represented probabilistically by a displacement hazard curve that is analogous to ground motion hazard curves. Thus the hazard curve was a plot of the frequency of exceeding a fault displacement value.



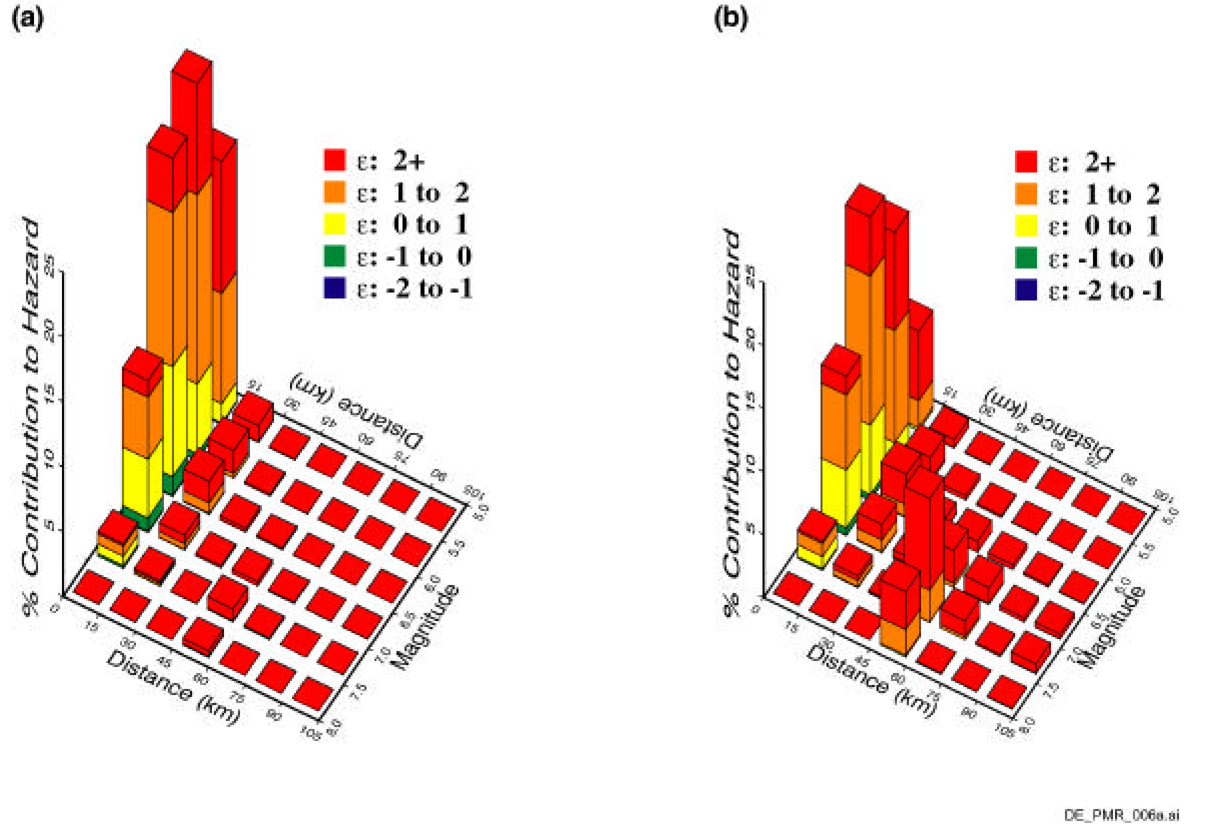
Source: Modified from CRWMS M&O 2000c, Figure 14a

NOTES: g = acceleration due to gravity, 9.8m/sec^2; Hz = cycles/sec or 1/sec.

Figure 2-13. Integrated Seismic Hazard Results: Horizontal Uniform Hazard Spectrum for 10^{-4} Exceedance Probability

Fault displacement hazard was evaluated at nine locations within the Yucca Mountain site area (CRWMS M&O 2000c, Figure 3). These locations were selected to span the range of known faulting conditions and ranged from block-bounding faults to small fractures and unfaulted rock. All the teams considered the points on the Bow Ridge and Solitario Canyon faults as subject to principal faulting hazard. A few teams also considered some potential for principal faulting hazard at two locations on two intrablock faults. The teams varied widely in their assessments of the probability that distributed faulting could occur in future earthquakes at points that are located off of the block-bounding faults. These assessments were based on fault orientation, cumulative slip, and structural relationship. Four teams considered that the probability of displacement at a point in intact rock due to the occurrence of a future earthquake is essentially zero (i.e., the probability that a new fault will form is essentially zero).

With the exception of the block-bounding Bow Ridge and Solitario Canyon faults, the mean displacements are 0.1 cm or less at 10^{-5} annual exceedance probability. At 10^{-5} probability, the mean displacements are 8 and 32 cm, respectively, for these two faults. Sites not located on a block-bounding fault—such as sites on the intrablock faults, other small faults, shear fractures, and intact rock—are estimated to have displacements significantly less than 0.1 cm for annual frequencies as low as 10^{-5} (Wong and Stepp 1998, Table 8-1).



Source: Modified from CRWMS M&O 2000c, Figure 16

NOTE: ε is the number of standard deviations away from median ground motion. Both plots are for 10^{-4} annual exceedance probability.

Figure 2-14. Magnitude-Distance-Epsilon Disaggregation of Mean Seismic Hazard for (a) 5 to 10 Hz and (b) 1 to 2 Hz Horizontal Spectral Acceleration at 10^{-4} Annual Exceedance Frequency

2.1.3.3 TSPA-VA Analysis of Seismicity

Prior to the TSPA-VA, analysis of seismic hazard had not been systematically included in TSPAs, although some calculations had been made (Gauthier et al. 1996). Disruptive events seismic hazard analyses for TSPA-VA examined the subissues and acceptance criteria of the NRC *Issue Resolution Status Report Key Technical Issue*: *Structural Deformation and Seismicity* (NRC 1999a). However, because of the limited scope of seismic activity analysis, the TSPA-VA contributed little toward addressing the subissues of the IRSR (CRWMS M&O 1998b, p. 10-57).

Potential effects of seismic activity that were identified by the TSPA-VA from previous work included: (1) vibratory ground motion and fault displacement from earthquakes, (2) changes in site hydrologic properties including changes in water table elevation and changes in groundwater flow patterns, and (3) indirect effects such as alteration of groundwater flow paths caused by faulting or dike emplacement in the SZ (DOE 1998a, p. 4-88).

The indirect effects scenario for faulting was excluded (screened out) from TSPA-VA analysis by the same sensitivity study that supported screening out indirect effects of volcanism. Section 2.1.2.3 contains a discussion of the indirect effects of volcanism from a dike emplaced in the SZ. The only seismic effect analyzed in TSPA-VA was that for rockfall on a WP caused by vibratory ground motion initiated by an earthquake. Changes in site hydrologic properties were not analyzed by TSPA-VA, except for the aspects of changes in groundwater flow patterns included in the sensitivity analysis for indirect effects.

The rockfall scenario was one in which rocks, jarred free of the emplacement drift roof by vibratory ground motion, fell on WPs (DOE 1998a, p. 4-90). Thermal-mechanical stresses from drift excavation and the heat generated by the waste were also considered as a source of rock quality weakening that could contribute to rockfall (DOE 1998a, p. 10-57). The drift's concrete liners were assumed to have failed within a few hundred years (DOE 1998a, p. 4-90). The result of rockfall was conceptualized either as a split in the WP that allowed immediate access of air and water or as dents in the package that provided locations for accelerated corrosion and premature failure of the WP. Damage to WP walls was a function of time since closure because of thinning by corrosion (DOE 1998a, p. 4-91).

The results of TSPA-VA seismic activity modeling showed that, if the outer barrier (corrosion allowance material) was not corroded, a rock larger than allowed by any observed combination of fractures measured in the Exploratory Studies Facility was needed to damage the WP (DOE 1998a, p. 4-92). Results showed that, when the outer barrier and half of the inner barrier were corroded, a rock of the dimensions allowed by fractures observed in the Exploratory Studies Facility could damage the WP; however, this scenario would require more than 100,000 years of wet corrosion conditions. Calculations showed almost no effect on repository performance for the first 1,000,000 years, and over a 10,000-year period "the probability of rockfall causing a WP to split open was essentially zero" (DOE 1998a).

For TSPA-SR some TSPA-VA scenarios are being re-examined. Water table rise is the subject of FEP 1.3.07.02.00 in the Project FEPs database, and the screening argument for it is contained in *Features, Events, and Processes in UZ Flow and Transport* (CRWMS M&O 2000q). Rockfall is re-examined for analyses where there is no backfill in the potential repository design.

2.1.4 Features, Events, and Processes Analysis for Disruptive Events

The following discussion serves two purposes. It is a summary of the FEPs scenario development process currently in use by the DOE and employed for disruptive events FEPs analysis for TSPA-SR. Because it is taken from the disruptive events FEPs AMR (CRWMS M&O 2000h, Section 1), it also serves as part of the summary of that AMR in this disruptive events PMR. The rest of the summary for the disruptive events FEPs AMR is provided in two other sections of this PMR. The summary of FEPs analysis results for FEPs associated with volcanism is contained in Section 3.1.6, and FEPs associated with tectonics, seismicity and structural deformation are summarized in Section 3.2.4. The following discussion is a summary of the origin and methods of the FEPs scenario development process for TSPA-SR.

Under the provisions of the DOE's Interim Guidance (Dyer 1999), the DOE must provide a reasonable assurance that the performance objectives for the potential repository can be achieved for a 10,000-year postclosure period. This assurance must be demonstrated in the form of a PA that:

1. Identifies the FEPs that might affect the performance of the geologic repository

2. Examines the effects of such FEPs on the performance of the geologic repository

3. Estimates the expected annual dose to a specified receptor group. The PA must also provide the technical basis for inclusion or exclusion of specific FEPs from the assessment.

2.1.4.1 FEPs Identification and Analysis

The development of a comprehensive list of FEPs relevant to the YMP is an ongoing process based on site-specific information, guidance documents, and proposed regulations. The YMP FEPs Database (CRWMS M&O 2000j, Chapter 2) contains 1,797 entries derived from the following sources:

- General FEPs from other radioactive waste disposal programs
- YMP-specific FEPs identified in YMP literature
- YMP-specific FEPs identified in technical workshops
- External review of the YMP FEP list.

The YMP FEPs list was initially populated with FEPs compiled by radioactive waste programs in the United States and other nations. The Nuclear Energy Agency of the Organization for Economic Co-operation and Development maintains an electronic FEP database that currently contains 1,261 FEPs from seven programs, which represents the most complete international attempt to compile a comprehensive list of FEPs potentially relevant to radioactive waste disposal (SAM 1997). The 1,261 FEPs identified by these programs have been organized by the Nuclear Energy Agency FEP database working group into a hierarchical structure of layers, headings, and categories. The structure of the Nuclear Energy Agency FEP database is defined by a total of 150 layers, categories, and headings. The Nuclear Energy Agency FEP database currently exists in draft form only, but the publications of the seven disposal programs that contributed FEPs to the compilation contain descriptions of the FEPs. References to these programs can be found in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h, Section 1.2).

The YMP FEP database used the same structure as the Nuclear Energy Agency FEP database; however, Barr (1999) identified an additional heading relevant to YMP (the Nuclear Criticality heading in the Geologic Environment category) that was not in the Nuclear Energy Agency database. Therefore, the YMP FEP database was modified to include a total of 151 layers, categories, and headings. Each of the layers, categories, and headings is an individual entry in the YMP FEP database as are the 1,261 FEPs incorporated from the Nuclear Energy Agency database. Consequently, the YMP FEP database, prior to the addition of YMP-specific FEPs, contained a total of 1,412 entries.

The YMP FEPs list was supplemented with YMP-specific FEPs identified in past YMP work during site characterization and preliminary PAs (Barr 1999). The supplemental entries resulted from a search of YMP literature in 1998 and identified 292 additional FEP entries. Relevant FEPs from the 1,704 entries identified from the Nuclear Energy Agency database and YMP literature were then taken to a series of technical workshops where the relevant FEPs were reviewed and discussed by subject matter experts within the project. As a result of these discussions, workshop participants proposed 82 additional YMP-specific FEPs.

Subsequent reviews of the comprehensive YMP FEPs list by subject matter experts were performed in 1999 and 2000 in association with the development of the FEPs AMRs. During preparation of the FEPs AMR, subject matter experts reviewed the existing FEPs relevant to their subject area and, where necessary, identified new or missing FEPs. The review and documentation process identified 9 additional FEPs.

An interim version of the YMP FEPs list was provided to the NRC in association with the NRC/DOE Appendix 7 Meeting on the FEPs Database held September 8, 1999. A subsequent NRC audit of the interim version of the YMP FEPs list identified two FEPs to be added to the YMP FEPs list.

The FEPs have been classified as "primary" and "secondary" FEPs and have been assigned to various PMRs. The primary FEPs, of which there are 310, are the coarsest aggregation of FEPs suitable for screening for the YMP. They are the FEPs for which the project proposes to develop detailed screening arguments. The descriptions of primary FEPs are such that they include the secondary FEPs. Secondary FEPs are either completely redundant or can be reasonably aggregated into a single primary FEP. By working to the primary FEP description, the subject matter experts assigned to the primary FEP also addressed all relevant secondary FEPs, and arguments for secondary FEPs can be included in the primary FEP analysis and disposition.

For screening and analysis, the FEPs have been assigned to different groups based on the PMR structure so that the analysis, screening decision, and TSPA disposition reside with the subject matter experts in the relevant disciplines. The TSPA recognizes that FEPs have the potential to affect multiple facets of the Project, may be relevant to more than one PMR, or may not fit neatly within the PMR structure. For example, many FEPs affect waste form, WP, and the EBS. Rather than create multiple separate FEPs, the FEPs have been assigned, as applicable, to one or more process model groups, which are responsible for the PMRs.

2.1.4.2 FEPs Screening Process

The first step in the scenario development process was the identification and analysis of FEPs. The second step in the scenario development process included the screening of each FEP against project criteria.

Each FEP is screened against the guidance, assumptions, or specific criteria stated in the DOE's Interim Guidance (Dyer 1999); the NRC's proposed rule 10 CFR 63 (64 FR 8640), and the U.S. Environmental Protection Agency's (EPA's) proposed rule 40 CFR Part 197 (64 FR 46976) (CRWMS M&O 2000h, Section 1.3). The screening criteria are discussed in more detail in the

AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h, Section 1.3); they are summarized here:

- Is the FEP specifically ruled out by the guidance or proposed regulations, or contrary to the stated guidance or regulatory assumptions?
- Does the FEP have a probability of occurrence of less than 10^{-4} in 10^{4} years?
- Will the resulting expected annual dose be "significantly changed" or the results of the PA be "changed significantly" by omission of the FEP? (Note: "significantly changed" and "changed significantly" are undefined terms in the DOE Interim Guidance and in the NRC's and EPA's proposed regulations. "No significant changes" is inferred to be equivalent to having no or negligible effect.)

The screening criteria contained in DOE's Interim Guidance (Dyer 1999), proposed rule 10 CFR 63 (64 FR 8640), and proposed 40 CFR Part 197 (64 FR 46976) are relevant to many of the FEPs. FEPs that are contrary to DOE's Interim Guidance or specific proposed regulations, regulatory assumptions, or regulatory intent are excluded from further consideration. Examples include the explicit exclusion of consideration of all but a stylized scenario to address treatment of human intrusion (Dyer 1999; and proposed rule 10 CFR 63 [64 FR 8640, Section 113d]), assumptions about the critical group to be considered in the dose assessment (Dyer 1999; and proposed rule 10 CFR 63 [64 FR 8640, Section 115]), and the intent that the consideration of "the human intruders" be excluded from the human intrusion assessment (proposed rule 10 CFR 63 [64 FR 8640, Section XI: Human Intrusion]). Figure 2-15 provides a summary of the FEPs screening process for TSPA-SR.

Probability estimates used in the FEPs screening process are based on technical analysis, either by consideration of bounding conditions or a quantitative analysis, and, in some cases, involve a formalized expert elicitation such as seismic- and volcanic-hazard probabilities. Probability arguments, in general, use quantitative information about the spatial and temporal scale of the event or process, the magnitude of the event or process, and the response of the repository features to such events and processes. For the TSPA the probability of an event is the product of the hazard level (e.g., for a seismic event this would be the magnitude of ground motion expressed as an annual exceedance probability) and the resulting impact (e.g., unacceptable damage to the drip shield expressed as a fragility probability).

The last of the three criteria stated above allow FEPs to be excluded from further consideration if the expected annual dose would not be "significantly changed" by their omission (i.e., on the basis of low consequence to dose). The terms "significantly changed" and "changed significantly" are undefined terms in the NRC's and EPA's proposed regulations. These terms are inferred for FEPs screening purposes to be equivalent to having no, or negligible, effect. Because the relevant performance measures differ for different FEPs (e.g., effects on performance can be measured in terms of changes in concentrations, flow rates, travel times, or other measures as well as overall expected annual dose), there is no single quantitative test of "significance."

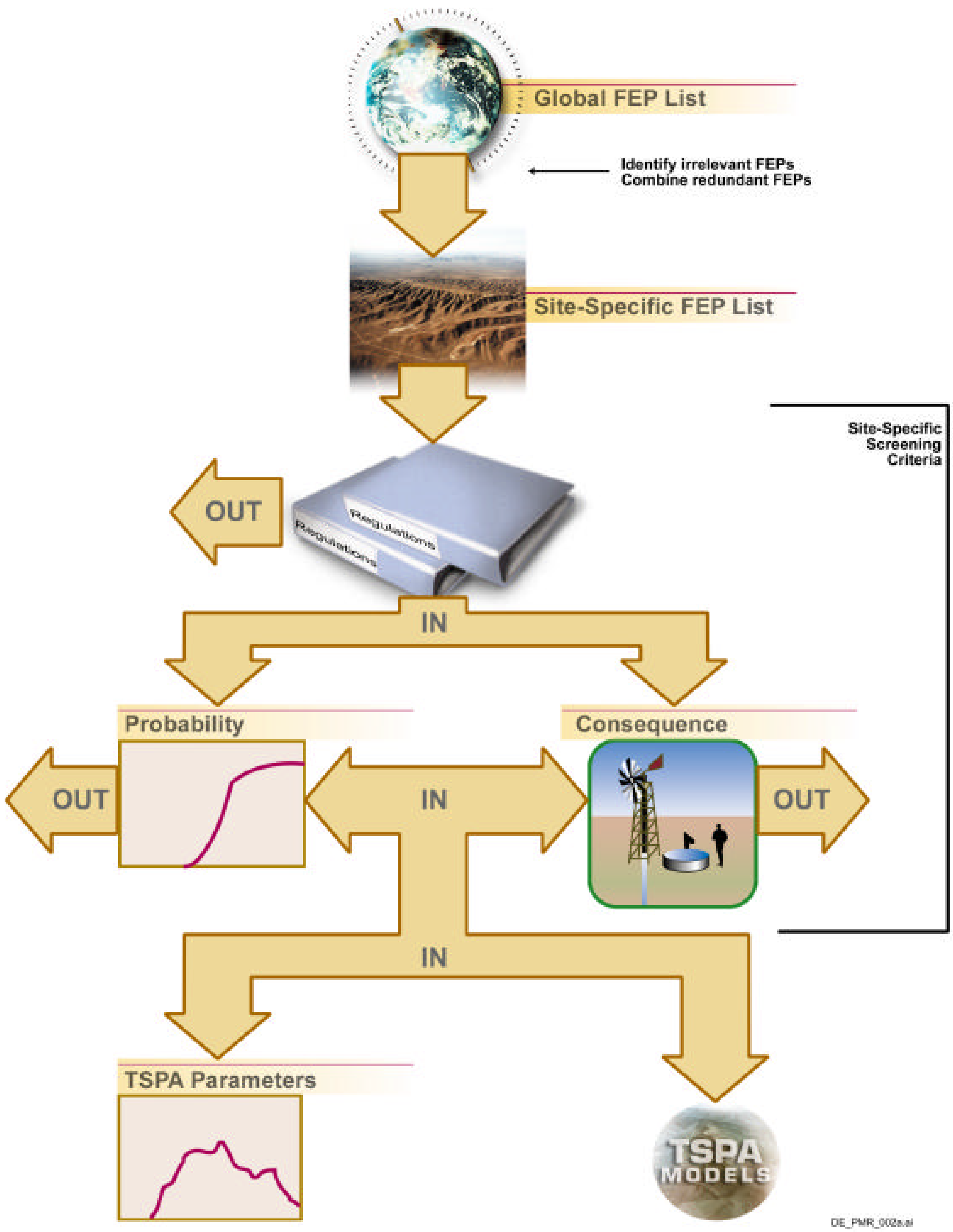


Figure 2-15. Screening Process for Features, Events, and Processes from Global List to TSPA-SR

Some low-consequence arguments are made by demonstrating that a particular FEP has no effect on an intermediate performance measure in the TSPA. If a FEP can be shown to have negligible impact on UZ or SZ flow and transport, waste package integrity, or other components of the EBS or natural barrier system, then there is no mechanism for the FEP to result in an increase in the calculated dose in the TSPA. Consequently, the FEP has a negligible impact on the PA, and the FEP can be excluded on the basis of low consequence to dose. For example, by demonstrating that including a particular waste form has no effect on the concentrations of radionuclides transported from the repository in the aqueous phase, it is also demonstrated that including this waste form in the inventory would not affect other performance measures, such as doses, that are dependent on concentration. Explicit modeling of the characteristics of this waste form could, therefore, be excluded from further consideration in the TSPA for instances where concentration of radionuclides has a primary impact on dose.

Various methods to demonstrate negligible impact include the use of site-specific data, TSPA sensitivity analyses, expertise of subject matter experts (including, in some cases, the expert elicitation process), natural analogues, modeling studies outside the TSPA, and reasoned arguments based on literature research. More complicated processes, such as igneous activity, may require detailed analyses conducted specifically for the YMP.

Based on the three screening criteria stated previously, the screening decision for the FEP is then determined to be either "Included in the TSPA-SR" or "Excluded from the TSPA-SR." If a FEP is determined to be "Included in the TSPA-SR," the TSPA must specifically include the effects of the FEP in calculations or, as appropriate, in the human intrusion scenario. Inclusion of an FEP in the TSPA signifies that the potential effects of the FEP on repository performance are included in performance-related and dose-related calculations. If the screening decision is "Included in the TSPA-SR," the FEP can be considered either in the nominal scenario (i.e., the scenario that contains all expected FEPs and no disruptive FEPs), in the disruptive scenario (i.e., any scenario that contains all expected FEPs and one or more disruptive FEPs), or, as appropriate, in the human intrusion scenario. Expected FEPs are those FEPs "Included in the TSPA-SR" that, for the purposes of the TSPA, are assumed to occur with a probability equal to one during the period of performance.

Because the primary FEPs are the coarsest aggregate suitable for analysis, situations may result in which a given primary FEP contains some secondary FEPs that are "Included in the TSPA-SR" and some that are "Excluded from the TSPA-SR." Or, in some situations, existing conditions (such as existing fracture characteristics) are "Included in the TSPA-SR," but changes to the existing conditions (such as changes in fracture aperture) have been demonstrated to be of low consequence to dose and are considered as "Excluded from the TSPA-SR." In these situations, the screening decision will specify which elements are included and which are excluded.

In some instances, a screening decision may be based on data that is designated in a source document as preliminary to be verified (TBV), on preliminary calculations or conclusions, or on very strong and reasoned arguments that remain to be verified. In these instances, the "Excluded from the TSPA-SR" screening decision will specify the disposition as "Preliminary." Although not expected, the disruptive events FEPs AMR (CRWMS M&O 2000h) and its conclusions regarding FEPs screening decisions may, therefore, be affected by technical product input information that requires confirmation.

2.1.4.3 Disruptive Events FEPs

The primary purpose of the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) was to identify and document the analysis, screening decision, and TSPA disposition, or screening argument, for the 21 FEPs that were recognized as disruptive events FEPs (see Table 2-1).

Table 2-1. Primary Disruptive Events FEPs

YMP FEP Database Number	FEP Name
1.2.01.01.00	Tectonic activity—large scale
1.2.02.01.00	Fractures
1.2.02.02.00	Faulting
1.2.02.03.00	Fault movement shears waste container
1.2.03.01.00	Seismic activity
1.2.03.02.00	Seismic vibration causes container failure
1.2.03.03.00	Seismicity associated with igneous activity
1.2.04.01.00	Igneous activity
1.2.04.02.00*	Igneous activity causes changes to rock properties
1.2.04.03.00	Igneous intrusion into repository
1.2.04.04.00	Magma interacts with waste
1.2.04.05.00	Magmatic transport of waste
1.2.04.06.00	Basaltic cinder cone erupts through the repository
1.2.04.07.00	Ashfall
1.2.10.01.00*	Hydrologic response to seismic activity
1.2.10.02.00	Hydrologic response to igneous activity
2.1.07.01.00	Rockfall (large block)
2.1.07.02.00	Mechanical degradation or collapse of drift
2.2.06.01.00*	Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock
2.2.06.02.00*	Changes in stress (due to thermal seismic, or tectonic effects) produce change in permeability of faults
2.2.06.03.00*	Changes in stress (due to seismic or tectonic effects) alter perched water zones

Source: CRWMS M&O 2000h, Section 1.1, Table 1

NOTE: *FEP may also be addressed in related FEPs reports as noted in the YMP FEP Database (CRWMS M&O 2000j).

Table 2-2 provides a summary of the disruptive events FEPs screening decisions and the basis for “Excluded from the TSPA-SR” decisions and includes both primary and secondary FEPs. A detailed discussion of the screening process is presented in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h, Section 6). Shaded FEPs are Primary; others are Secondary.

Table 2-2. Summary of Disruptive Events FEPs Screening Decisions for Primary and Secondary FEPs

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.01.01.00	*Tectonic activity—large scale*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.01	*Folding, uplift or subsidence lowers facility with regard to current water table*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.02	*Tectonic change to local geothermal flux causes convective flow in SZ and elevates water table*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.03	*Tectonic folding alters dip of tuff beds, changing percolation flux*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.04	*Uplift or subsidence changes drainage at the site, increasing infiltration*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.05	*Uplift and subsidence*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.06	*Effect of plate movements*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.07	*Plate movement/tectonic change*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.08	*Uplift and subsidence*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.09	*Regional vertical movements*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.10	*Regional tectonic activity*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.11	*Regional tectonics*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.12	*Regional horizontal movements*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.13	*Regional uplift and subsidence*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.01.01.14	*Geological (events)*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.01.00	*Fractures*	*Included in the TSPA-SR: existing characteristics / Excluded from the TSPA-SR (Preliminary): changes to characteristics*	*Does not satisfy a screening criterion / Low consequence to dose*
1.2.02.01.01	*Change in fracture properties*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.01.02	*Fracturing*	*Excluded from the TSPA-SR*	*Low consequence to dose*

Table 2-2. Summary of Disruptive Events FEPs Screening Decisions for Primary and Secondary FEPs (Continued)

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.02.02.00	*Faulting*	Included in the TSPA-SR*: existing characteristics/* Excluded from the TSPA-SR (Preliminary)*: changes in fault properties and new faults*	*Does not satisfy a screening criterion / Low consequence to dose for changes to existing characteristics, and low probability for new faults*
1.2.02.02.01	*Faulting*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.02.02	*Fault generation*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.02.03	*Fault activation*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.02.04	*Movements along small-scale faults*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.02.05	*Faulting/Fracturing*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.02.06	*Formation of new faults*	*Excluded from the TSPA-SR*	*Low probability*
1.2.02.02.07	*Fault movement*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.02.08	*Normal faulting occurs or exists at Yucca Mountain*	Included in the TSPA-SR*: existing characteristics/* Excluded from the TSPA-SR*: changes in fault properties*	*Does not satisfy a screening criterion / Low consequence to dose for changes to existing characteristics,*
1.2.02.02.09	*Strike-slip faulting occurs or exists at Yucca Mountain*	Included in the TSPA-SR*: existing characteristics/* Excluded from the TSPA-SR *: changes in fault properties and new faults*	*Does not satisfy a screening criterion / Low consequence to dose for changes to existing characteristics, and low probability for new faults*
1.2.02.02.10	*Detachment faulting occurs or exists at Yucca Mountain*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.02.11	*Dip-slip faulting occurs at Yucca Mountain*	Included in the TSPA-SR*: existing characteristics/* Excluded from the TSPA-SR*: changes in fault properties and new faults*	*Does not satisfy a screening criterion / Low consequence to dose for changes to existing characteristics, and low probability for new faults*
1.2.02.02.12	*New fault occurs at Yucca Mountain*	*Excluded from the TSPA-SR*	*Low probability*

Table 2-2. Summary of Disruptive Events FEPs Screening Decisions for Primary and Secondary FEPs (Continued)

YMP FEP Database Number	***FEP Name***	***Screening Decision***	***Screening Basis***
1.2.02.02.13	*Old fault strand is reactivated at Yucca Mountain*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.02.14	*New fault strand is activated at Yucca Mountain*	*Excluded from the TSPA-SR*	*Low probability*
1.2.02.02.15	*Movements along major faults*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.02.16	*Faulting (large scale, in geosphere)*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.02.02.17	*Faulting exhumes waste container*	*Excluded from the TSPA-SR*	*Low probability*
1.2.02.03.00	*Fault movement shears waste container*	*Excluded from the TSPA-SR*	*Low probability*
1.2.03.01.00	*Seismic activity (Note: Includes faulting, hydraulic heads, recharge and discharge zones, rock stresses, drift integrity)*	Excluded from the TSPA-SR*:* (Preliminary) *indirect effects /* Excluded from the TSPA-SR (Preliminary)*: breaching of drip shield, and of the emplacement pallet and WP /* Included in the TSPA-SR*: fuel-rod cladding damage*	*Low consequence to dose / Low consequence to dose / Does not satisfy a screening criterion*
1.2.03.01.01	*Earthquakes*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.03.01.02	*Earthquakes*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.03.01.03	*Earthquakes*	Excluded from the TSPA-SR*: indirect effects /* Excluded from the TSPA-SR*: breaching of drip shield, and of the emplacement pallet and WP /* Included in the TSPA-SR *fuel-rod cladding damage*	*Low consequence to dose / Low consequence to dose / Does not satisfy a screening criterion*
1.2.03.01.04	*Seismicity**	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.03.01.05	*Seismicity*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.03.01.06	*Seismicity*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.03.01.07	*Seismic activity*	*Excluded from the TSPA-SR*	*Low consequence to dose*

Table 2-2. Summary of Disruptive Events FEPs Screening Decisions for Primary and Secondary FEPs (Continued)

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.03.02.00	*Seismic vibration causes container failure*	Excluded from the TSPA-SR (Preliminary)*: breaching of drip shield, and of the emplacement pallet and WP* / Included in the TSPA-SR *fuel-rod cladding damage*	*Low consequence to dose / Does not satisfy a screening criterion*
1.2.03.02.01	*Container failure induced by microseisms associated with dike emplacement*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.03.03.00	*Seismicity associated with igneous activity*	Excluded from the TSPA-SR*: indirect effects* / Included in the TSPA-SR*: fuel-rod cladding damage*	*Low consequence to dose / Does not satisfy a screening criterion*
1.2.04.01.00	*Igneous activity (Note: Also effects on faults, topography, rock stresses, groundwater temperatures and drift integrity)*	*Included in the TSPA-SR: direct effects / Excluded from the TSPA-SR: indirect effects*	*Does not satisfy a screening criterion / Low consequence to dose*
1.2.04.01.01	*Volcanism*	*Included in the TSPA-SR: direct effects / Excluded from the TSPA-SR: indirect effects*	*Does not satisfy a screening criterion / Low consequence to dose*
1.2.04.01.02	*Magmatic activity*	*Included in the TSPA-SR: direct effects / Excluded from the TSPA-SR: indirect effects*	*Does not satisfy a screening criterion / Low consequence to dose*
1.2.04.01.03	*Magmatic activity*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.01.04	*Magmatic activity*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.01.05	*Volcanic activity*	*Included in the TSPA-SR: direct effects / Excluded from the TSPA-SR: indirect effects*	*Does not satisfy a screening criterion / Low consequence to dose*
*1.2.04.02.00 **	*Igneous activity causes changes to rock properties*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.04.02.01	*Dike provides a permeable flow path*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.04.02.02	*Dike provides a barrier to flow*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.04.02.03	*Volcanic activity in the vicinity produces an impoundment*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.04.02.04	*Igneous activity causes extreme changes to rock geochemical properties*	*Excluded from the TSPA-SR*	*Low consequence to dose*

Table 2-2. Summary of Disruptive Events FEPs Screening Decisions for Primary and Secondary FEPs (Continued)

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.04.02.05	*Intrusion (magmatic)*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.04.02.06	*Dike related fractures alter flow*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.04.02.07	*Magmatic activity*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.04.03.00	*Igneous intrusion into repository*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.03.01	*Sill provides a permeable flow path*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.03.02	*Sill provides a flow barrier*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.03.03	*Sill intrudes repository openings*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.03.04	*Volcanism*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.03.05	*Intruding dikes*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.04.00	*Magma interacts with waste*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.04.01	*Magmatic volatiles attack waste*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.04.02	*Dissolution of spent fuel in magma*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.04.03	*Dissolution of other waste in magma*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.04.04	*Heating of waste container by magma (without contact)*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.04.05	*Failure of waste container by direct contact with magma*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.04.06	*Fragmentation (Note: with subsequent damage to WP)*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.05.00	*Magmatic transport of waste*	Excluded from the TSPA-SR*: transport in liquid magma and other types of transport /* Included in the TSPA-SR*: transport through eruptive events*	*Low consequence to dose/ Does not satisfy a screening criterion*
1.2.04.05.01	*Direct exposure of waste in dike apron*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.04.05.02	*Volatile radionuclides plate out in the surrounding rock*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.04.05.03	*Entrainment of SNF in a flowing dike*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.04.06.00	*Basaltic cinder cone erupts through the repository (Note: Also entraining waste)*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*

Table 2-2. Summary of Disruptive Events FEPs Screening Decisions for Primary and Secondary FEPs (Continued)

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.04.06.01	*Vent jump (formerly called "wander")*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.06.02	*Vent erosion*	*Included in the TSPA-SR*	*Does not satisfy a screening criterion*
1.2.04.07.00	*Ashfall*	*Included in the TSPA-SR / Excluded from the TSPA-SR: pyroclastic flow*	*Does not satisfy a screening criterion / Low consequence to dose*
1.2.10.01.00 *	*Hydrologic response to seismic activity*	*Excluded from the TSPA-SR (Preliminary)*	*Low consequence to dose*
1.2.10.01.01	*Fault movement pumps fluid from SZ to UZ (seismic pumping)*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.02	*Fault creep causes short term fluctuation of the water table*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.03	*New faulting breaches flow barrier controlling large hydraulic gradient to the north*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.04	*Normal faulting produces a trap for laterally moving moisture in the Tiva Canyon unit*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.05	*Head driven flow up from carbonates*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.06	*Seismically-induced water table changes*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.07	*Fault pathway through the altered Topopah Spring basal vitrophyre*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.08	*Fault movement connects tuff and carbonate aquifers*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.09	*Fault establishes pathway through UZ*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.10	*Fault establishes pathway through the SZ*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.11	*Fluid supplied by a fault migrates down the drift*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.12	*Fault intersects and drains condensate zone*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.01.13	*Flow barrier south of the site blocks flow, causing water table to rise*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.02.00	*Hydrologic response to igneous activity (Note: Includes groundwater flow directions; water level, chemistry, temperature; change in rock properties)*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.02.01	*Interaction of WT (water table) with magma*	*Excluded from the TSPA-SR*	*Low consequence to dose*
1.2.10.02.02	*Interaction of unsaturated zone pore water with magma*	*Excluded from the TSPA-SR*	*Low consequence to dose*

Table 2-2. Summary of Disruptive Events FEPs Screening Decisions for Primary and Secondary FEPs (Continued)

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
2.1.07.01.00	Rockfall (large block)	Excluded from the TSPA-SR (Preliminary)	Low consequence to dose
2.1.07.01.01	Rockbursts in container holes	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.01.02	Cave ins	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.01.03	Cave in (in waste and EBS)	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.01.04	Roof falls	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.02.00	Mechanical degradation or collapse of drift	Excluded from the TSPA-SR (Preliminary)	Low consequence to dose
2.1.07.02.01	Stability (in waste and EBS)	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.02.02	Mechanical (events and process in the waste and EBS)	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.02.03	Rockfall stopes up fault	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.02.04	Rockfall (rubble)(in waste and EBS)	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.02.05	Mechanical failure of repository	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.02.06	Subsidence/collapse	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.02.07	Vault collapse	Excluded from the TSPA-SR	Low consequence to dose
2.1.07.02.08	Creeping rock mass	Excluded from the TSPA-SR	Low consequence to dose
2.2.06.01.00 *	Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock	Excluded from the TSPA-SR (Preliminary)	Low consequence to dose
2.2.06.01.01	Stress-produced porosity changes	Excluded from the TSPA-SR	Low consequence to dose
2.2.06.01.02	Stress-produced permeability changes	Excluded from the TSPA-SR	Low consequence to dose
2.2.06.01.03	Stress-produced permeability changes	Excluded from the TSPA-SR	Low consequence to dose
2.2.06.01.04	Regional stress regime	Excluded from the TSPA-SR	Low consequence to dose
2.2.06.01.05	Regional stress regime	Excluded from the TSPA-SR	Low consequence to dose
2.2.06.01.06	Regional stress regime	Excluded from the TSPA-SR	Low consequence to dose
2.2.06.01.07	Stress field (in geosphere)	Excluded from the TSPA-SR	Low consequence to dose

Table 2-2. Summary of Disruptive Events FEPs Screening Decisions for Primary and Secondary FEPs (Continued)

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
2.2.06.01.08	*Changes in stress field*	*Excluded from the TSPA-SR*	*Low consequence to dose*
2.2.06.01.09	*Changes in regional stress*	*Excluded from the TSPA-SR*	*Low consequence to dose*
2.2.06.01.10	*Stress changes - hydrogeological effects*	*Excluded from the TSPA-SR*	*Low consequence to dose*
*2.2.06.02.00 **	*Changes in stress (due to thermal, seismic, or tectonic effects) produce change in permeability of faults*	*Excluded from the TSPA-SR (Preliminary)*	*Low consequence to dose*
2.2.06.02.01	*Aseismic alteration of permeability along and across faults*	*Excluded from the TSPA-SR*	*Low consequence to dose*
2.2.06.02.02	*Fracture dilation along faults creates zones of enhanced permeability*	*Excluded from the TSPA-SR*	*Low consequence to dose*
2.2.06.02.03	*Relaxation of thermal stresses by fault movement*	*Excluded from the TSPA-SR*	*Low consequence to dose*
2.2.06.02.04	*Seismically-stimulated release of thermo-mechanical stress on bounding faults*	*Excluded from the TSPA-SR*	*Low consequence to dose*
2.2.06.02.05	*Relaxation of thermal stresses by fault movement*	*Excluded from the TSPA-SR*	*Low consequence to dose*
*2.2.06.03.00 **	*Changes in stress (due to seismic or tectonic effects) alter perched water zones)*	*Excluded from the TSPA-SR*	*Low consequence to dose*
2.2.06.03.01	*Perched zones develop as a result of stress change*	*Excluded from the TSPA-SR*	*Low consequence to dose*

Source: CRWMS M&O 2000h, Section 7

NOTES: Shaded items are primary FEPs; others are secondary FEPs.
**These FEPs are addressed by multiple FEP AMRs, see the YMP FEP Database (CRWMS M&O 2000j). SNF = spent nuclear fuel.*

FEPs screening provided decisions regarding which analyses will be included in TSPA-SR. Section 2.1.4.2 of this disruptive events PMR explains the screening criteria and the significance of the "Included in the TSPA-SR" and "Excluded from the TSPA-SR" screening decisions.

The next section of Chapter 2 discusses the overall approach to disruptive events analysis for SR that evolved from previous work and from technical workshops held in early 1999. A discussion is provided regarding how disruptive events analyses work together to produce the current approach. The impact of design on analyses is also discussed at a summary level.

2.2 APPROACH TO DISRUPTIVE EVENTS ANALYSIS FOR SR

Site characterization work, expert elicitations, TSPAs, and other analyses and calculations by the YMP and other researchers discussed in previous sections of this chapter contributed to developing the bases for the analysis of volcanism and seismicity for TSPA-SR. In addition, a series of Project workshops held in February of 1999 brought together analysts from disciplines that had contributed to disruptive events analysis in three areas: volcanism, seismicity, and criticality.

At the workshops the results of TSPA-VA analyses and major unresolved KTIs were discussed. Potential analytical approaches were discussed and the outcome led to development of work plans that were used as the bases for the technical development plans that support TSPA-SR AMRs. An initial list of FEPs from the YMP FEPs database, sorted into subject areas, was distributed at the workshops for discussion of association to process model topics. A list of the FEPs to be addressed in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) was selected from this process.

In April of 1999 the procedural framework that guides the TSPA-SR was significantly reworked and the AMR and PMR structure was developed. The structure of disruptive events analysis was developed to be based on eight AMRs and one calculation.

The feeds from one AMR or calculation to another (or others) and support from AMRs or calculations performed outside of the disruptive events group is illustrated in Figures 2-16 and 2-17. Section 2.2.2 contains a summary level discussion of the relationship between the analyses and calculations shown in Figures 2-16 and 2-17. The tables in Sections 3.1.1 through 3.1.5 and Sections 3.2.1 through 3.2.3 that summarize the inputs and outputs of the AMRs and calculation contain further information to support the figures.

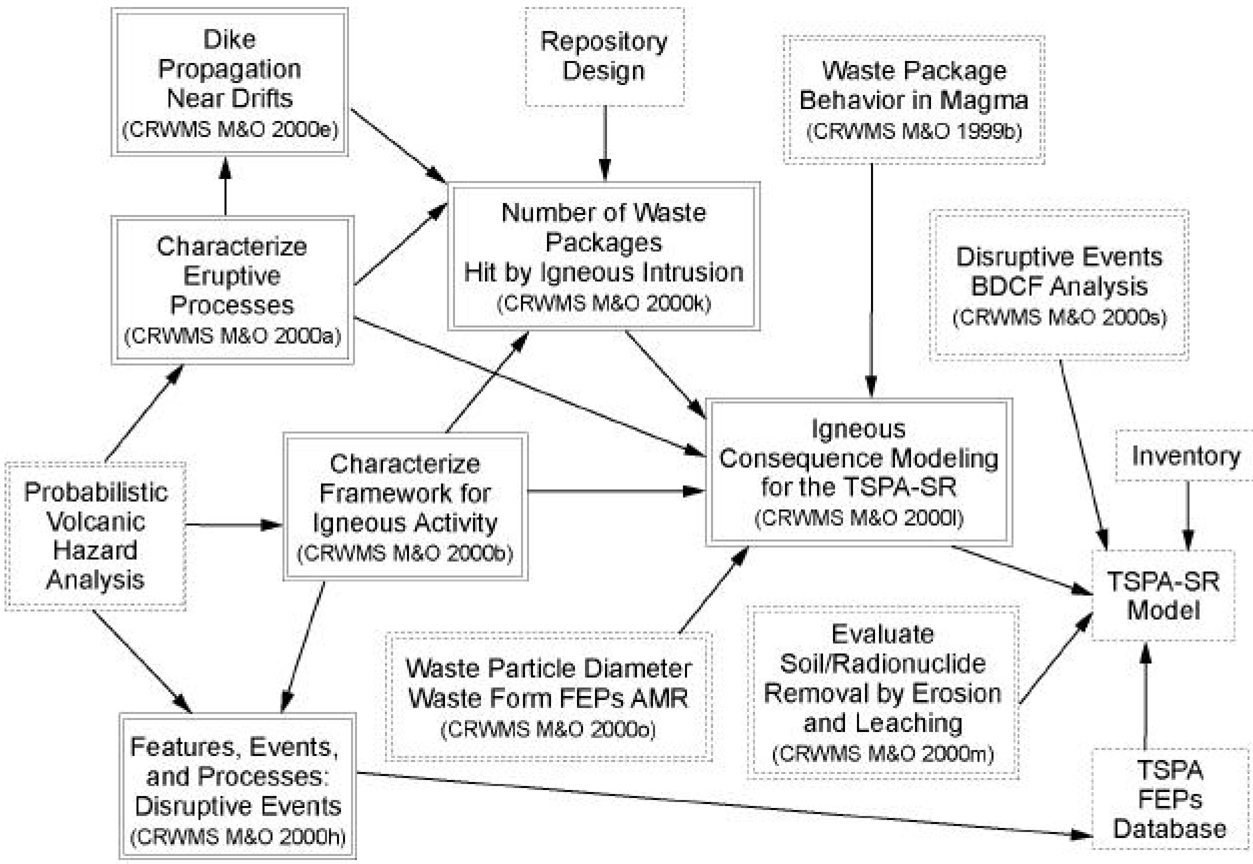
Each AMR is written to the outline provided in procedure AP-3.10Q, in which input data are listed in Chapter 4, assumptions are given in Chapter 5, the analysis is provided in Chapter 6, and conclusions are listed in Chapter 7. Conclusions include outputs that are used in other AMRs (as parameters ready for use or to be further reduced), or are used directly in the TSPA analysis. The following discussion will provide other summary level information regarding the overall approach to analysis, including the approach to incorporation of new data and how the analyses responded to design changes over the period of development of the AMRs.

The issue of how and whether to incorporate new data into analyses as the data become available was addressed in a letter to the NRC (Brocoum 1997). The following discussion of treatment of new data is taken from that letter. Although the letter was written after a technical exchange on the topic of igneous activity, the new-data policy applies to new data for all topics.

At the time of the PVHA and PSHA expert elicitations the experts had access to all the applicable data that had been developed by the YMP and other researchers. It was recognized that new data would continue to be collected that might be relevant to the hazard analysis results; therefore, a policy was established by the DOE to review new data. The letter describing the approach to new data states (Brocoum 1997, p. 1):

> DOE intends to evaluate the significance of new data using sensitivity analyses that evaluate, first, whether the data represent new findings that were not considered by the expert panel and, second, given that the data do represent new findings, evaluate the impact on the PDF [probability distribution function].

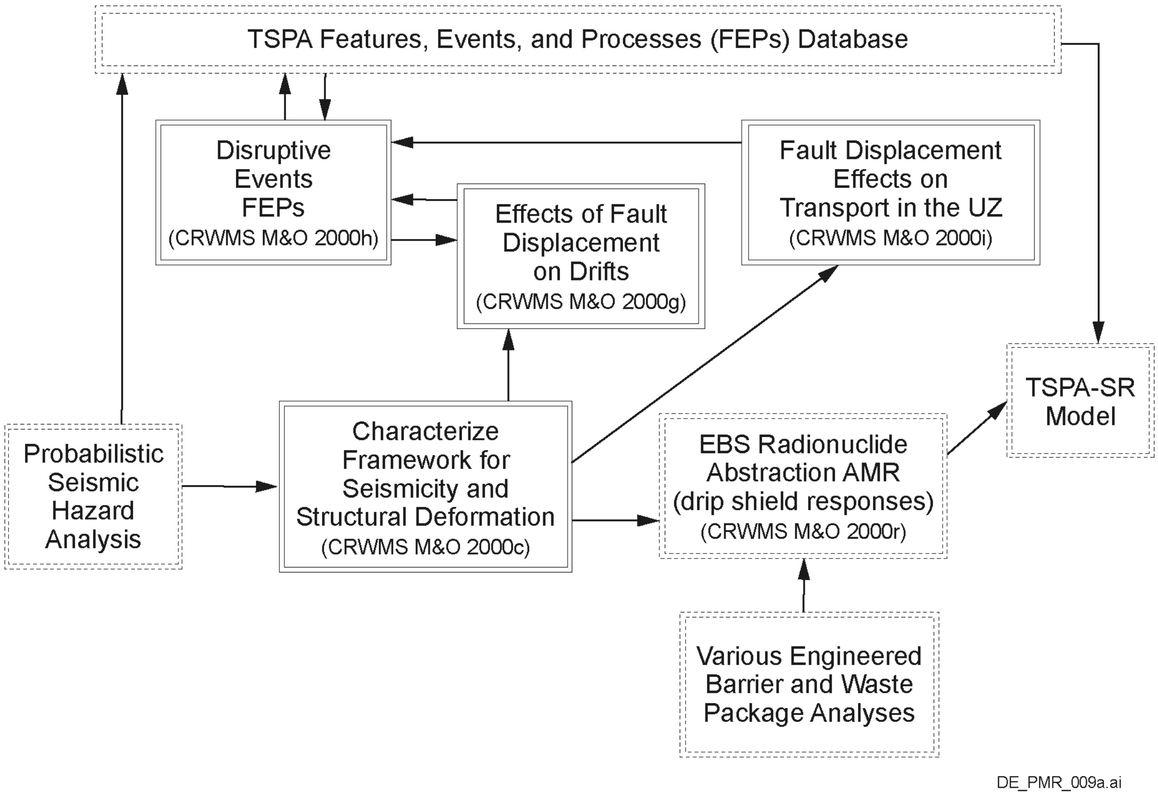
Both expert elicitations produced hazard curves presented as probability distribution functions. The DOE position is to examine the new data in comparison to data that was available to the experts during the elicitations. If these new data are consistent with the data already considered by the experts, then they are not evaluated further. New data considered to be new findings and potentially significant are to be further evaluated through sensitivity analyses.



NOTES: Titles of documents may be abbreviated in the flow chart.
Information for excluded FEPs is sent to the FEPs database. Treatment of included FEPs is variable and is described in TSPA-SR documentation.

Figure 2-16. Disruptive Events AMR Relationships and Feeds to TSPA-SR for Volcanism Analysis; Activities External to Disruptive Events PMR Group of AMRs and Calculation Shown in Dashed Boxes

Regarding the TSPA-SR, several studies that could be significant to the hazard analysis for volcanism are being examined by the YMP. The studies include: *Summary Report Magnetic and Gravity Study of the Yucca Mountain Area, Nevada* (Earthfield Technology 1995); *CNWRA Ground Magnetic Surveys in the Yucca Mountain Region, Nevada (1996-1997)* (Magsino et al. 1998); and "Anomalous Strain Accumulation in the Yucca Mountain Area, Nevada" (Wernicke et al. 1998). These studies present data related to the tectonic framework of the Yucca Mountain region that also control the volcanic regime, so they could be considered new data for both volcanism and tectonics (covered in the topic of seismicity for disruptive events). The disruptive events AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* provides a discussion of some of the issues presented by these studies (CRWMS M&O 2000b, Section 6). The data in the studies mentioned in this paragraph were found not to have a significant impact on the results of the PSHA or the PVHA and therefore did not affect TSPA-SR parameters.



NOTE: Titles of documents may be abbreviated in the flow chart.

Figure 2-17. Disruptive Events AMR Relationships and Feeds to TSPA-SR for Seismicity Analysis; Activities External to Disruptive Events PMR Group of AMRs and Calculation Shown in Dashed Boxes

New data are often viewed as information that may support an alternative conceptual model for FEPs relevant to volcanism and seismicity that could potentially affect the potential repository. Examination of alternative conceptual and analytical models was a requirement for development of the AMRs and the calculation, which contain discussions of these models as appropriate. To provide a defensible technical basis for the approach taken in the AMRs, these documents include assumptions and the associated rationale, data with a traceable source and QA record, discussion of the analytical approach and supporting calculations, and final conclusions.

The design, at the time the initial disruptive events AMR development plans for the TSPA-SR were produced, did not include drip shields or backfill. The disruptive events analysis for ground motion (seismicity), therefore, included potential damage to WPs from rockfall. The AMR analyzing rockfall (CRWMS M&O 2000f**)** that was started under the disruptive events PMR was completed under the EBS PMR (CRWMS M&O 2000v) and was retained when the proposed design changed to include backfill, eliminating the disruptive effects of rockfall. For the scenario with no backfill, no drip shield, and rockfall caused by ground motion, the TSPA-VA analysis was as a disruptive event. When backfill and drip shields were added to the proposed design, the TSPA-SR analysis concludes that rockfall could be screened out of the TSPA on the basis of low consequence. Ground motion damage to the drip shield and cladding, however, were identified as part of the nominal case analysis. With the backfill removed, as in the currently proposed design, potential impacts of rockfall on drip shields are being evaluated for TSPA-SR and will be covered by changes to the AMRs following the interim change notice procedure in AP-3.10Q. Further enhancements to the drip shield design have led to a reconsideration of the need to include ground motion damage to the drip shield in the TSPA-SR. At the time of production of this PMR, analysis was still ongoing.

The issue of changing design concepts over time also affected the approach for analysis of the potential effects of volcanism on the potential repository. The analytical approach for the disruptive events AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) was significantly affected. The analysis for initial version of the AMR was performed during the time when the design included backfill and drip shields. With backfill and drip shields in the drifts, the flow of magma down the drifts from a dike was assumed to be impeded by the pile-up of backfill and drip shields pushed by the magma. Having these design elements in place caused a shorter distance of flow down the drifts than could occur if the drifts contained only WPs. Without drip shield and backfill the results may change when a new calculation is performed. A change in the results of the dike propagation analysis will impact the results of the downstream calculation *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k) and the AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l). Changing the results of the downstream AMRs could impact the amount of radionuclides available for transport by either the volcanic eruption release or igneous intrusion groundwater release (WPs compromised by magma, but not in eruptive conduit) pathways.

2.2.1 Disruptive Events Not Included in Current Analysis

Criticality was analyzed as a disruptive event for TSPA-VA, but is not included in the disruptive events group of analyses for TSPA-SR. Human intrusion, which is specified as a disruptive event in proposed 10 CFR 963.17(b) (64 FR 67054), was analyzed as a disruptive event for TSPA-VA, and results showed increased dose rates that were within the variability of base case results (DOE 1998a, p. 4-102). For TSPA-SR, human intrusion will be analyzed as a stylized scenario (following proposed 10 CFR 963.17[b] [64 FR 67054]), and the results will be contained in the TSPA-SR documentation.

The Repository Safety Strategy, in describing the postclosure safety case, includes a list of potentially disruptive processes and events (CRWMS M&O 2000p, pp. 2-8 to 2-13). The disruptive events for the Repository Safety Strategy are consistent with those identified in proposed 10 CFR 963.17(b) (64 FR 67054).

The Repository Safety Strategy list was developed from knowledge of the geologic setting, prominence in past technical reviews, and public concern. Potentially disruptive events in the Repository Safety Strategy include: human intrusion, water table rise to the level of the repository, seismic activity, igneous activity, waste-generated disruptions (including criticality), early failure of engineered barriers (caused by manufacturing defects), and drift collapse (rockfall). The manner and location of analysis for all of these, except early failure of engineered barriers, is discussed in this disruptive events PMR. Early failure of engineered barriers will not be treated as a disruptive event for TSPA-SR, although an approximation of "juvenile failure" of WPs was included in the base case for TSPA-VA (DOE 1998a, p. 4-11).

2.2.2 Approach to Volcanism Analysis

The approach to volcanism analysis supporting TSPA-SR is a fully probabilistic treatment of consequences with volcanic eruption release and igneous intrusion groundwater release analysis included in the TSPA-SR model. The dose from releases due to volcanism is treated as part of the expected annual dose by combining the probability-weighted sum of the dose due to volcanic sources and the nominal dose. Overall, the TSPA-SR analysis approach for the potentially disruptive effects of waste releases caused by volcanism represents an improvement over the same calculation for TSPA-VA in several ways. The technical basis for the analysis is improved by the addition of more consequence data, the addition of an analysis for the distance magma moves down drifts during intrusion, improvement of the probability distribution calculations relevant to dikes, and the recommendation of a greater number of ASHPLUME runs (CRWMS M&O 2000l). In the following discussion of the roles and interactions of the AMRs the improvements in the analysis will be mentioned in association with the AMR description.

Figure 2-16 (Section 2.2) shows the flow of information from volcanism analysis from the disruptive events AMRs to each other and to output for the TSPA-SR. The following discussion provides a summary level description of the role of the AMRs and calculation in the analysis. Sections in Chapter 3 of this disruptive events PMR provide a more detailed description of each AMR and the calculation.

The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) summarizes the geologic framework significant to volcanism in the Yucca Mountain region based largely on the PVHA (CRWMS M&O 1996). The AMR also provides a summary of the PVHA process and results (see Section 2.1.2.2, above). The AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) provides detailed information on eruptive processes including the nature of dike systems, magma properties, and properties of erupted material. Together these two AMRs provide the framework conceptual information and parameter values for volcanic FEPs analysis that were used by the downstream AMRs.

The AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) develops an analysis for the interaction of a hypothetical basaltic dike with an emplacement drift, drip shields, and backfill. The analysis also examines the nature of a potential shock wave into the drift from the gases exsolving from the magma as it first encounters the relatively lower pressure of the drift environment. These analyses provide an estimate of the number of WPs that would be affected by magma and gases entering the drift as part of the intrusive phase of a volcanic event. The output provided the number of packages engulfed by magma and a description of the thermal and chemical environment to which the WPs might be exposed.

All three of the disruptive events AMRs just described provide input to the calculation *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k). Specifically, these AMRs provide assumptions relevant to dikes, conduits, number of eruptive centers, and the number of packages hit on either side of an intrusive dike. The calculation then provides outputs for the number of packages hit by both intrusive and eruptive volcanic events based on the TSPA-SR design EDA II, Design B (CRWMS M&O 1999a) and the SRSL design (no backfill) (CRWMS M&O 2000z).

The outputs from the disruptive events AMRs just discussed eventually become inputs to the disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l), either through a direct input or as inputs that go through other AMRs first. The primary activity of the igneous consequence AMR is to receive outputs from the disruptive events AMRs and some other YMP data and, if necessary, perform operations that output the data in a suitable form for use in TSPA-SR models. Some data are passed through without being further reduced. In the process of organizing data and turning it into suitable parameter form, the AMR develops two conceptual models, one for volcanic eruptive release and the other for igneous intrusive groundwater release. These models are the "modeling concept" conceptual models and are compatible with the geologic conceptual models developed by the disruptive events framework and eruptive processes AMRs.

Calculations of dose from igneous activity for TSPA-SR depend on inputs from analyses outside the disruptive events PMR group, as is shown in Figure 2-16. Data on waste particle diameter are provided by an analysis within the FEPs AMR in the waste form analysis group (CRWMS M&O 2000o). Appendix A to this PMR is Attachment l, "An Estimate of Fuel-Particle Sizes for Physically Degraded Spent Fuel Following a Disruptive Volcanic Event Through The Repository," to the Waste Form FEPs AMR and contains the result of the waste particle size analysis. This analysis provides waste particle size information with a technical basis that is improved over that used for TSPA-VA. The calculation *Waste Package Behavior in Magma* (CRWMS M&O 1999b), performed within the Waste Package PMR group of calculations, provides information on the behavior of WPs in the magmatic thermal environment. The results show that failure could occur by lid separation or failure of tensile strength and that the WPs would be close to failure at magmatic temperatures, even without significant prior thinning by corrosion.

Other AMRs that contribute to calculation of dose from igneous activity are developed within the Biosphere PMR group of calculations. The AMR *Disruptive Event Biosphere Dose Conversion Factor Analysis* provides biosphere dose conversion factors for radionuclide sources that arise from the volcanic eruption release (CRWMS M&O 2000s). A biosphere dose conversion factor is a multiplier used to convert a radionuclide concentration at the geosphere/biosphere interface (i.e., waste particle concentration in ash/human tissue interface) into a dose that a human would experience, with units expressed in terms of annual dose (i.e., effective dose equivalent) per unit concentration (DOE 1998a, p. A-4). Another AMR in the Biosphere PMR group of analyses, *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2000m), contributes to the dose calculation for igneous activity. This AMR takes the ash/waste particle fallout from a volcanic eruption release and performs calculations for radionuclide-in-soil concentrations that could result if the fallout was plowed into the soil during agricultural activity and/or subjected to natural erosional and leaching processes. The radionuclide inventory for dose calculation for volcanic eruption release is the same as for the nominal case.

The igneous intrusion groundwater release scenario is modeled by using information from the disruptive events AMR *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k) to get the number of packages hit by magma during an igneous intrusion. It is assumed that the contents become available for transport in groundwater after the magma cools. The AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) passes along the number of packages compromised to the TSPA-SR calculation, where the inventory for that number of packages is supplied and the radionuclide transport (with source term increased over the nominal case) is modeled by the UZ flow and transport model until the water table is reached and the radionuclides are passed over to the SZ flow and transport model. These models are run within the TSPA-SR (CRWMS M&O 2000l, Section 7).

The AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) contains screening arguments and decisions for a list of FEPs that are a subset of the YMP FEPs database list. Sections 2.1.4, 3.1.6 and 3.2.4 in this disruptive events PMR contain details of how the disruptive events FEPs list was determined and a discussion of results from both volcanism (Section 3.1.6) and seismicity and structural deformation (Section 3.2.4) FEPs analyses. For some FEPs, the disruptive events FEPs AMR contains references to the contents of other disruptive events AMRs to support screening arguments. For example, the disruptive events AMRs *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g) and *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i) provide the technical basis for screening out certain scenarios, and that information supports the "Excluded from the TSPA-SR" argument for several FEPs in the YMP FEPs database.

2.2.3 Approach to Seismicity and Structural Deformation Analysis

A seismic event is defined as a disruptive event in proposed 10 CFR 963.17(b) (64 FR 67054). However, backfill in the EDA II design (CRWMS M&O 1999a) allows the disruptive events scenario where ground motion causes rockfall to be screened out through the FEPs process (CRWMS M&O 2000h, FEP 2.1.07.01.00). Therefore, the approach to the analysis of the effects of ground motion for TSPA-SR (for a design with backfill) would be treated as part of the nominal case through effects addressed in modeling under *Waste Package Degradation Process Model Report* (CRWMS M&O 2000u) and *Engineered Barrier System Degradation, Flow, and Transport Process Model Report* (CRWMS M&O 2000v). For a design without backfill, SRSL (CRWMS M&O 2000z), seismic effects on drip shields would be examined (CRWMS M&O 2000r). Fault displacement effects are mitigated by setbacks from known faults in the design process and should not affect postclosure performance. The role of the two disruptive events AMRs that analyze potential fault displacement effects is discussed briefly below, and more detail is contained in Sections 3.2.2 and 3.2.3 of this disruptive events PMR. Section 3.3 of this PMR provides a discussion of how seismicity issues are approached for the YMP as a whole.

Figure 2-17 shows the flow of information from the disruptive events AMRs to output for the TSPA-SR or as input to support screening decisions for seismicity and structural deformation

FEPs. For a summary level description of the kind of information developed by the AMRs and passed along the pathways indicated by the arrows in Figure 2-17, see the sections in Chapter 3 that describe each AMR. For each AMR (except the disruptive events FEPs AMR) a table is presented with a summary of key points of the AMR analysis including inputs and outputs.

The AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c) summarizes the processes and results of the PSHA expert elicitation project that produced hazard curves for ground motion and fault displacement for the potential repository. A summary of the PSHA abstracted from the AMR is provided in Section 2.1.3.2 of this disruptive events PMR. The AMR also summarizes some aspects of the geologic framework significant to seismicity in the Yucca Mountain region, based on the PSHA. The seismicity framework AMR is summarized in Section 3.2.1 of this disruptive events PMR. This AMR does not originate any new outputs that are used directly as inputs by the disruptive events AMRs; rather the role of the AMR is to provide summary level information to support understanding of the tectonic framework supporting disruptive events analyses and to provide a roadmap to the PSHA. Figure 2-18 shows an example of how a conceptual model for a ground motion event, based on the PSHA, would be modeled in TSPA-SR as compared to the nominal condition.

The results of the PSHA are used by the disruptive events AMR that analyzed fault displacement effects as a source of data relevant to the nature of faults and their expected behavior in the repository area (CRWMS M&O 2000g). In a similar way, results of the PSHA analysis are used to support analysis of potential drip shield damage from ground motion in the AMR *EBS Radionuclide Transport Abstraction* (CRWMS M&O 2000r). That AMR provides an abstraction for the response of the drip shield to thermal and mechanical processes in the repository to the TSPA-SR model. The AMR also uses inputs from work performed under the *Engineered Barrier System Degradation, Flow, and Transport Process Model Report* (CRWMS M&O 2000v) and the *Waste Package Degradation Process Model Report* (CRWMS M&O 2000u) groups of analyses.

The disruptive events AMR *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g) evaluates the potential effects of fault displacement on emplacement drifts, including drip shields and WPs. The magnitude of fault displacement analyzed corresponds to an annual frequency of exceedance of 10^{-5}. Together with consideration of the maximum total Quaternary displacement on faults at Yucca Mountain, results of this analysis are used to support screening arguments for the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) for faulting FEPs, including the FEPs “Faulting” (1.2.02.02.00) and “Fault movement shears waste container” (1.2.02.03.00).

The disruptive events AMR *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i) evaluates the potential for changes to the hydrogeologic system caused by fault displacement to affect radionuclide transport in the UZ. The analysis looks at two end-member scenarios where strain from faulting is either distributed throughout the repository block between block-bounding faults or is localized to the area around a fault zone. The UZ three-dimensional (3-D) flow and transport model is used to run simulations to determine the effects of fracture aperture changes caused by strain from fault displacement. The results of this AMR provide support for screening arguments in the disruptive events FEPs AMR for the following FEPs: “Faulting” (1.2.02.02.00); “Seismic activity” (1.2.03.01.00); “Hydrologic response to seismic activity" (1.2.10.01.00); "Changes in stress produce change in permeability of faults" (2.2.06.02.00); "Tectonic Activity–large scale (1.2.01.01.00); "Fractures" (1.2.02.01.00); and "Changes in Stress (due to thermal, seismic, or tectonic effects) produce change in porosity and permeability of rock" (2.2.06.01.00).

Chapter 2 has provided an overview of how the disruptive events analyses were developed and how they are related to each other. Chapter 3 of this disruptive events PMR provides summary level discussions of the individual AMRs that support analysis of volcanism (Section 3.1) and seismicity and structural deformation (Section 3.2).

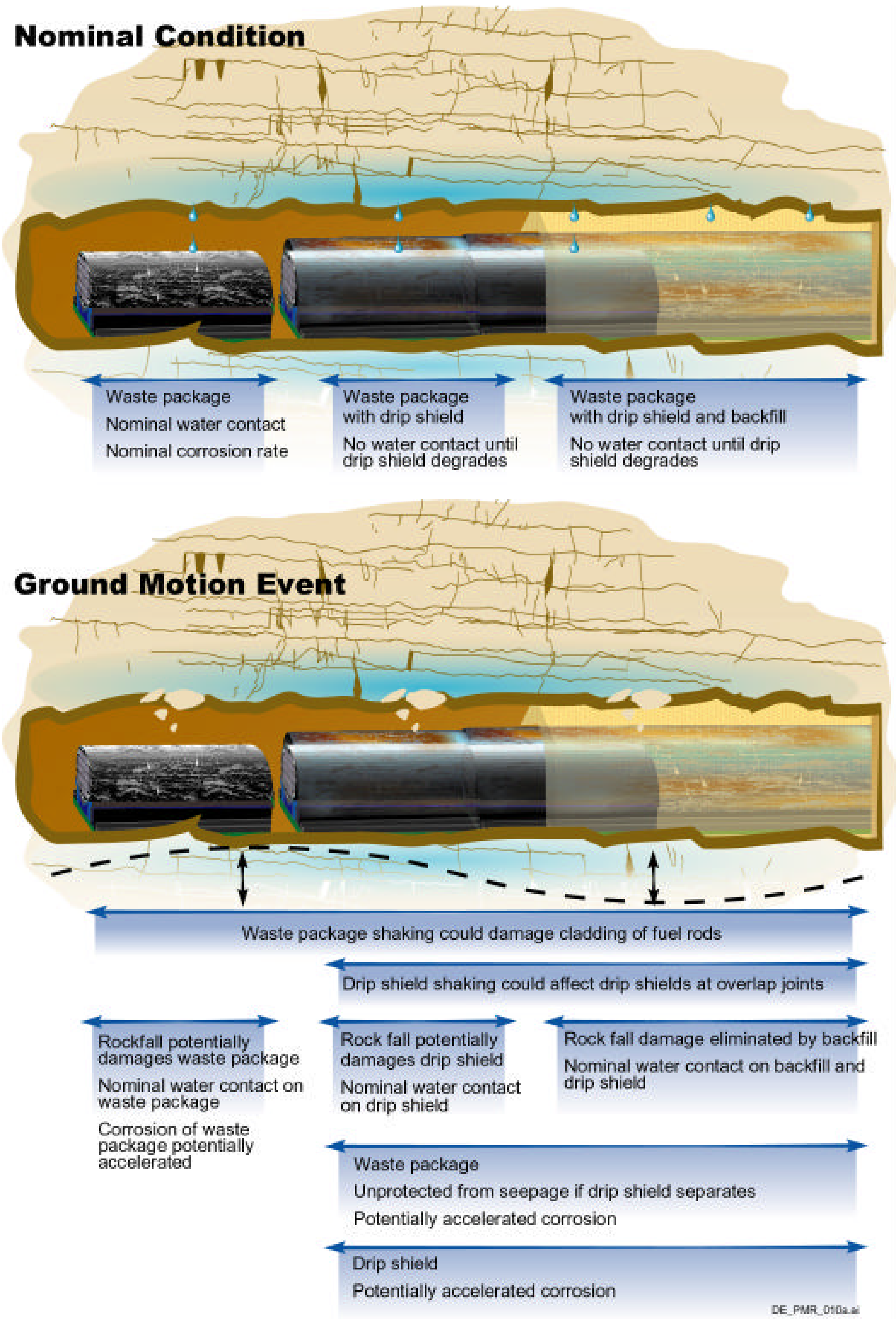


Figure 2-18. Ground Motion Event Potential Conceptual Models Compared to Nominal Condition for TSPA-SR for Designs with and without Backfill

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3. ANALYSES AND DEVELOPMENT OF CONCEPTUAL MODELS FOR DISRUPTIVE EVENTS

This Disruptive Events PMR summarizes the results of supporting AMRs and calculation that develop conceptual models, constrain processes, and develop parameters for use in the TSPA-SR analysis.

The eight AMRs and one calculation that support disruptive events analysis for TSPA-SR provide inputs that are used to analyze the probable behavior of the reference design engineered components in the presence of natural hazards that are considered to be “disruptive,” as distinguished from “nominal” in TSPA analysis. The exception is seismicity analysis in the absence of backfill, as previously discussed in Section 2.2.3 and further discussed in Section 3.3 of this Disruptive Events PMR.

The AMRs and calculation document the assumptions that are important to the analyses in Chapter 5 of the AMRs and Chapter 3 of the calculation. The assumptions in the AMRs and calculation are subjected to thorough interdisciplinary reviews to help ensure consistency among assumptions made in more than one document about a given parameter. In addition, this Disruptive Events PMR, which summarizes and integrates the results of the AMRs, is subjected to a review by a single review team, one of whose main objectives is to identify inconsistencies among the AMRs. These measures provide confidence that consistent assumptions are used appropriately among the various models that support TSPA-SR.

3.1 SUMMARY OF DISRUPTIVE EVENTS AMRs SUPPORTING ANALYSIS OF VOLCANISM

Section 2.2.2 contains an overview of how the disruptive events analyses for the effects of volcanism for TSPA-SR fit together. Figure 2-16 in Section 2.2 shows the relationship of the disruptive events volcanism AMRs to each other. Sections 3.1.1 through 3.1.6 provide summaries of the individual AMRs supporting the volcanism analysis for TSPA-SR. The ways in which the AMRs address NRC IRSR KTIs are discussed in Chapter 4 of this Disruptive Events PMR and are introduced briefly in the AMR summaries as applicable.

3.1.1 Characterize Framework for Igneous Activity at Yucca Mountain, Nevada

The purpose of the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) is twofold. The first purpose is to present a conceptual framework of igneous activity in the Yucca Mountain region consistent with the volcanic and tectonic history of the Yucca Mountain region and the assessment of this history by experts who participated in the PVHA (CRWMS M&O 1996). Conceptual models presented in the PVHA are summarized and extended in areas in which new information has been presented. Alternative conceptual models are discussed, as well as their impact on probability models. The relationship between volcanic source zones defined in the PVHA and structural features of the Yucca Mountain region is described based on discussions in the PVHA and studies presented since the PVHA. The second purpose is to present probability calculations needed for TSPA-SR based on PVHA inputs and revised to be consistent with the current repository design. The AMR provides a comparison of the repository footprint used in the PVHA with the repository footprint including primary and contingency blocks and a design that does not include backfill (CRWMS M&O 2000b, Figure 16). The probability of a basaltic dike intersecting the repository footprint is calculated in the AMR based on the repository footprint defined by EDA II, Design B (CRWMS M&O 1999a; Wilkins and Heath 1999) and based on the SRSL footprint 70,000 MTU no backfill design (CRWMS M&O 2000z). Probability distributions are also presented for the length and orientation of volcanic dikes within the repository footprint and for the number of eruptive centers (volcano conduits) located within the footprint, conditional on a dike intersection. These calculations were not included in the PVHA.

The PVHA report was the outcome of an expert elicitation and forms the foundation of much of the igneous analysis for the SR. The TSPA-SR requires consideration of both probability and consequence. The objective of the PVHA was to determine the probability of a basaltic dike intersecting the potential repository. The PVHA included discussion of some aspects of the consequences of a volcanic event, but not all the aspects required for the present analysis. The AMR provides additional analyses to support the description of the igneous activity consequence models.

The AMR addresses many of the concerns and comments raised by the NRC in the IRSR KTI for Igneous Activity. Specifically, the report clarifies event definitions and provides additional supporting documentation for probabilities for both intrusive and extrusive igneous activity. The framework presented emphasizes the appropriate selection of parameter distributions that affect probability models. It provides support for comparison of alternative conceptual frameworks and parameter selection within the overall framework of the volcanic history of the Yucca Mountain region. Review and analysis of the impacts of new data (e.g., geodetic and aeromagnetic data) to the results of the PVHA are discussed.

A summary of the key points for the AMR is provided in Table 3-1. These points are further discussed in the following section.

Table 3-1. Summary of Key Points for Disruptive Events AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*

Assumptions	
1	Quaternary volcanoes in the Yucca Mountain region are representative for calculation of consequences of an eruptive event, in particular the number of eruptive centers (conduits) per event.
2	Each hypothetical volcanic event where a dike intersects the repository footprint has at least one eruptive center located somewhere along the length of the dike.
3	The location of an eruptive center along the length of a dike or dike segment is defined by a uniform probability distribution. An alternative assumption, that the presence of the repository openings (drifts) results in the formation of at least one eruptive center within the repository footprint, is included in the analysis.
Inputs	
1	PVHA expert interpretations of volcanic hazard in the Yucca Mountain region.
2	Repository drift layout for EDA II Design B and SRSL 70,000 MTU no backfill design.
3	Location, age, and volume of volcanoes in the Yucca Mountain region.
4	Geochronology data.

Table 3-1. Summary of Key Points for Disruptive Events AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (Continued)

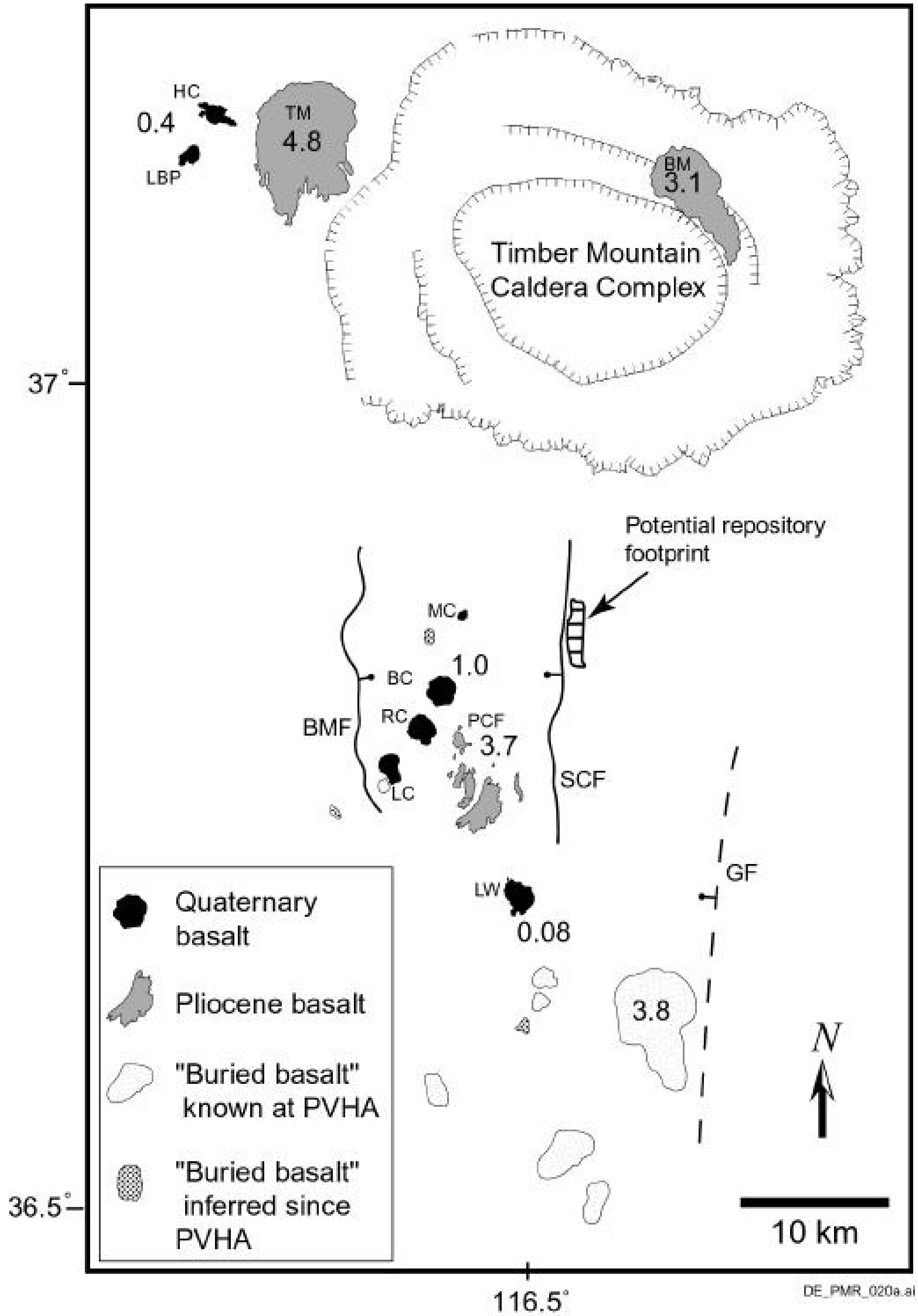
Outputs
1 Volcanic hazard to repository recalculated for footprints for EDA II and SRSL 70,000 MTU no backfill designs (PVHA results were calculated on different footprint).
a) Annual frequency of intersection of repository footprint by a dike associated with a volcanic event.
b) For each of six values of frequency of intersection:
- Conditional distributions for length and azimuth of intersecting dikes within the repository footprint.
- Conditional distributions for the number of eruptive centers (conduits) occurring within the repository footprint.
2 Event eruptive volume 0.002-0.14 km^3.
Overview of Analysis Method
1 Summarize process and results of PVHA project.
2 Use PVHA data to describe structural influences on points where magma is most likely to rise in the Yucca Mountain region.
3 Recalculate PVHA results for TSPA-SR repository footprint.
4 Produce conditional distributions for dike azimuth, dike lengths inside of repository, and number of eruptive centers.
AMRs or Other Analyses Receiving Outputs
1 *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k).
2 *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l).
Concepts Developed or Processes Constrained
Clarification of rationale for DOE conceptual models of volcanism and resultant hazard.

Source: CRWMS M&O 2000b

3.1.1.1 Key Points of AMR Analysis

The AMR *Characterize Framework for Igneous Activity at Yucca Mountain Nevada* (CRWMS M&O 2000b) provides a brief discussion of the two major types of volcanism that have occurred in the Yucca Mountain region. These were an early phase of Miocene silicic volcanism, the recurrence of which is considered unlikely and not of regulatory concern, and a more recent phase of Miocene and post-Miocene basaltic volcanism that is of regulatory concern (Reamer 1999, p. 5). A summary of the location, volume, and age of post-Miocene basalt centers in the Yucca Mountain region (see Figure 3-1 and Table 3-2) that are considered to be most significant to the assessment of volcanic hazard in the Yucca Mountain region is discussed in this AMR.

The AMR summarizes and extends the findings of the PVHA (see Section 2.1.2 for a description of the PVHA). For the PVHA, an expert panel was convened in 1995 to review all pertinent data relating to volcanism at Yucca Mountain and, based on these data, to quantify both the annual probability and associated uncertainty of a volcanic event intersecting a potential repository at Yucca Mountain. The data the experts reviewed were comprehensive, consisting of two decades of data collected by volcanologists who conducted studies to quantify the probability that a future volcanic eruption would disrupt the potential repository.



Source: CRWMS M&O 2000b, Figure 3

NOTES: Numbers by each volcano indicate approximate age in millions of years.

BC: Black Cone; BM: Buckboard Mesa; BMF: Bare Mountain Fault; GF: Gravity Fault; HC: Hidden Cone; LBP: Little Black Peak; LC: Little Cone; LW: Lathrop Wells; MC: Makani Cone; PCF: Pliocene Crater Flat; RC: Red Cone; SCF: Solitario Canyon Fault; TM: Thirsty Mesa.

Figure 3-1. Location and Age of Post-Miocene (< 5.3 my) Volcanoes (or Clusters Where Multiple Volcanoes Have Indistinguishable Ages) in the Yucca Mountain Region

Table 3-2. Estimated Volume and $^{40}Ar/^{39}Ar$ Age[a] of Quaternary Volcanoes in the Yucca Mountain Region

Volcano	Volume (km^3)[b]	Volume (km^3)[c]	Age (my)
Makani Cone	0.006		1.16-1.17
Black Cone	0.105	0.07	0.94-1.10
Red Cone	0.105		0.92-1.08
Little Cones	0.002	>0.01[d]	0.77-1.02
Hidden Cone	0.03		0.32-0.56
Little Black Peak	0.03		0.36-0.39
Lathrop Wells Cone	0.14		0.074-0.084

NOTES: [a] $^{40}Ar/^{39}Ar$ dates provide the most complete and self-consistent chronology data set for Quaternary volcanoes of the YMR. Other chronology methods may not provide consistent or accurate estimates of the time of eruption. See CRWMS M&O (2000b) for a discussion of this dating method.
[b] CRWMS M&O 2000b explains the source of this volume is from YMP data.
[c] Stamatakos et al. (1997 p. 327)
[d] Accounts for volume of buried flows detected by ground magnetic surveys.

In the volcanic framework AMR the results of the PVHA results are compared to published intersection probabilities. Results of the PVHA are discussed in Section 2.1.2.2. Most of the published intersection probabilities, including the mean intersection probability estimated in the PVHA, cluster at values slightly greater than 10^{-8} per year (CRWMS M&O 2000b, Table 6), indicating that the PVHA probability estimate is fairly robust given the range of alternative temporal and spatial models and event geometries considered in probability calculations.

An important issue in the PVHA and in alternative volcanic hazard assessments of the potential Yucca Mountain repository is the definition of a volcanic "event." Section 6.3.2 of the AMR discusses the definitions and parameters of a volcanic event and the implications for alternative probability calculations. For purposes of probability models developed in the PVHA and the AMR, a volcanic event is defined as a spatially and temporally distinct batch of magma ascending from the mantle forming a dike or system of dikes and possibly, surface eruptions from one or more vents (eruptive centers). A volcanic event is represented mathematically in the hazard calculation by a point in space located at the expected midpoint along the length of the dike or dike system associated with the event. The dike or dike system is represented by a linear element having length, azimuth, and location relative to the point event (CRWMS M&O 2000b, Figure 12). Although the PVHA experts considered volcanic events to possibly have an extrusive component (eruptive volcano) associated with the intrusive component (dike), the output of the PVHA was the annual frequency of intersection of the repository by an intrusive basaltic dike. The probability of an eruption, conditional on dike intersection, through the repository may be lower. The PVHA did not calculate the conditional probability that a dike intersecting the repository footprint would result in an extrusive volcanic eruption through the repository.

The NRC intersection probability values are based on the interpretation that every intersection of a vent alignment with the repository footprint results in an eruption through the repository (Reamer 1999, p. 57) and that the probability of intersection by shallow, intrusive events (that do not erupt) is necessarily higher, possibly by a factor of 2 to 5 (Reamer 1999, p. 60; CRWMS M&O 2000b, Figure 5). As discussed in the AMR, models for the distribution of vents (eruptive centers) along a dike (based on PVHA expert output and observed vent spacing in the Yucca

Mountain region) and uniform spatial distributions for eruptive center location along the length of the dike indicate that the eruption probability is always less than the dike intersection probability by a factor of approximately 2. An underlying assumption is that the presence of the repository openings (e.g., emplacement drifts) has no effect on the location of eruptive centers (CRWMS M&O 2000b). The NRC indicates that the pressure release occurring when ascending magma encounters an opening such as an emplacement drift may be sufficient to trigger formation of an eruptive center (e.g., the presence of the repository may focus development of eruptive centers within the repository) (Reamer 1999). The calculations presented in the AMR (CRWMS M&O 2000b) combine both of the above cases, which includes the NRC alternative model in which the conditional probability of forming at least one eruptive center within the repository footprint given an intersection is assumed to be 1.0. As a result, the expected frequency of eruptive disruption of the repository is 77 percent of the expected frequency of intrusive disruption of the repository (CRWMS M&O 2000b).

A related issue discussed in Section 6.3.2.1 of the AMR is whether dikes or dike systems can reach the near surface without any portion of the system erupting. The AMR concludes, based on observations of the Paiute Ridge intrusive/extrusive center, an appropriate analog in the Yucca Mountain region, that there is no evidence in the Yucca Mountain region geologic record to suggest that dike intrusions without accompanying eruptions occur 2 to 5 times more frequently than eruptions. Data from the San Rafael volcanic field on the western Colorado Plateau (Delaney and Gartner 1997) have been used to argue for higher intrusion probabilities (Reamer 1999, p. 60). As discussed in the AMR, an alternative interpretation is that the intrusion/extrusion ratio for the San Rafael volcanic field is closer to 1, an interpretation that is more consistent with the geologic record of the Yucca Mountain region, as demonstrated at the Paiute Ridge analog site.

Dike length is another parameter that can significantly affect intersection probabilities. The aggregate dike-length distribution derived from the PVHA has 5th percentile, mean, and 95th percentile values of 0.6, 4.0, and 10.1 kilometers, respectively (CRWMS M&O 2000b, Figure 4). These values are consistent with observed volcanic features in the Yucca Mountain region and with the length distribution for dikes measured in the San Rafael volcanic field (discussed above), which is sometimes used as a Yucca Mountain region analog by the NRC. Section 6.3.2.2 of the AMR notes that event lengths used in probability models by researchers from the University of Nevada, Las Vegas (e.g., Smith et al. 1990, pp. 81, 87) and the NRC (Reamer 1999, Figures 29, 30) correspond to the tails of the dike length distributions assessed by the experts in the PVHA. The maximum length value used by Smith et al. (1990) is based on comparison to data from a relatively large volume volcanic field that is not analogous in terms of volume to Quaternary volcanism near Yucca Mountain. The range of maximum event length values (10 to 20 km) used in NRC probability models (Reamer 1999, Figures 29, 30), is comparable to the maximum dike lengths assessed by the PVHA experts. However, the NRC's use of a uniform distribution for half-length results in a much greater weighting in NRC probability models for dike lengths that represent the 95th or greater percentile values assessed by the ten PVHA experts.

The conceptual model of volcanism, including how and where magmas form, and what processes control the timing and location of magma ascent through the crust to form volcanoes, has a fundamental impact on how probability models are formulated and the consequent results of probability models (e.g., Smith et al. 1990, pp. 83, 85 to 88; CRWMS M&O 1996, Section 4.3; Reamer 1999, Figures 29, 30). Section 6.3.3 of the AMR (CRWMS M&O 2000b) describes how the PVHA experts distinguished between deep (mantle source) and shallow (upper crustal structure and stress field) processes when considering different scales (regional and local) of spatial control on volcanism. The AMR also reviews the mechanistic model relating mantle melting and lithospheric extension that has recently been proposed for the Yucca Mountain region by the NRC (Reamer 1999, Section 4.1.5.3.2). This model is used as a geologic basis for weighting spatial density models based on crustal density variations across the Yucca Mountain region. As discussed in the AMR, the NRC probability model, which relies on spatial density functions weighted by crustal density (Reamer 1999, Section 4.1.6.3.3), may not be compatible with observations of volcano distribution within the Yucca Mountain region. The AMR suggests a possible alternative method of weighting spatial density models by estimated percent of extension within the Crater Flat Basin (e.g., Fridrich et al. 1999, Figure 5). This model ties probability models more directly to the geologic processes of faulting and extension that many researchers agree exert an important geologic control on volcano location (Smith et al. 1990, p. 83; CRWMS M&O 1996, Appendix E, pp. AM-5, MS-2; Reamer 1999, Section 4.1.3.3.3, p. 47).

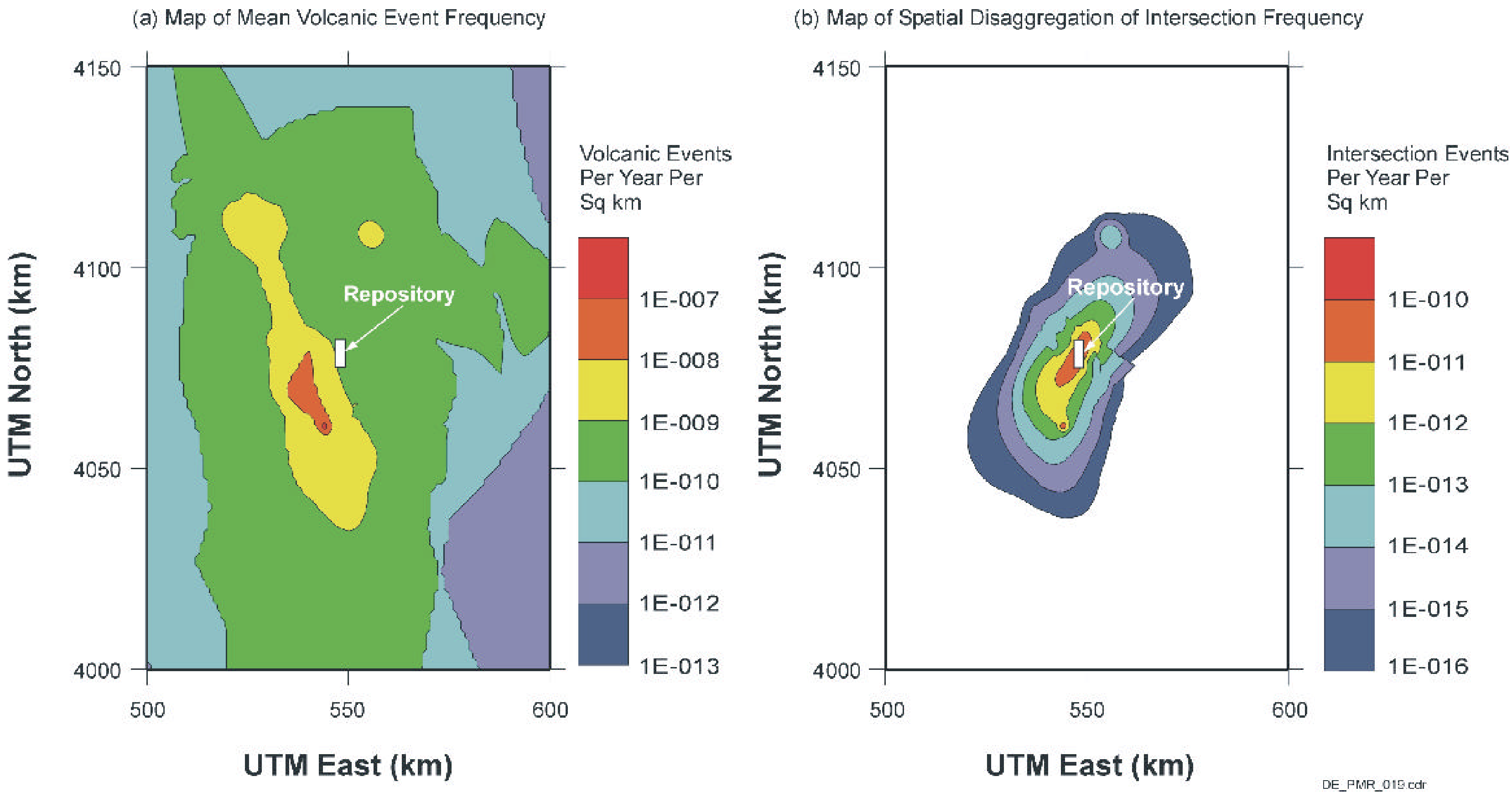
A summary of the internal structure of the Crater Flat basin and the correlation of the structural characteristics of the basin to the locations of post-Miocene basaltic centers is discussed in Section 6.4 of the AMR (CRWMS M&O 2000b). It is noted that the post-Miocene basaltic centers lie within the southwestern part of the basin (CRWMS M&O 2000b, Figure 7). This portion of the basin is coincident with the zone of greatest transtensional deformation, between the hinge line of the basin and the Bare Mountain fault, suggesting that this extensional zone controlled the ascent of basalt through the upper crust (Fridrich et al. 1999, p. 210). The hinge line proposed by Fridrich (1999, p. 177) marks a transitional boundary between a less deformed portion of the basin to the east (including Yucca Mountain) and a more deformed portion of the basin to the west, where all post-Miocene volcanism within the basin occurs. The hinge line does not represent a geologic structure (such as a fault), and does not represent a physical barrier that would preclude volcanism occurring in the eastern portion of the basin. The youngest volcano in the Crater Flat basin, the approximately 74,000 to 84,000-year-old Lathrop Wells volcano, lies between the southern ends of the Windy Wash and Stagecoach Road faults, the most active site of late Quaternary faulting in the Crater Flat basin (Fridrich et al. 1999, p. 211). Thus, there is a close spatial and temporal relationship between sites of tectonism and volcanism throughout the Crater Flat Basin (Fridrich et al. 1999, p. 211). The AMR observes that restriction of three episodes of post-Miocene volcanism to the transtensional zone in the Crater Flat basin suggests that volcanism is less likely to occur at Yucca Mountain, which lies outside the transtensional zone in an area where no post-Miocene volcanism has occurred (Fridrich et al. 1999, p. 210).

The AMR (Section 6.4) also describes the relationship between volcanic source zones defined in the PVHA and the current understanding of structural controls on volcanism in the Yucca Mountain region as described above. Many models of the experts related the areas of greatest likelihood for future volcanic activity to the region where previous volcanism has occurred and in which extensional deformation has been and continues to be greatest, i.e., to the southwestern portion of the Crater Flat Basin (CRWMS M&O 2000b, Figures 9a, 9b). Analysis by the NRC also indicates that the highest likelihood of future volcanic activity is in the southwestern Crater

Flat Basin (Reamer 1999, Sections 4.1.5.4, 4.1.6.3.3, Figure 28). Given that the southern and the southwestern portion of the Crater Flat Basin is the most extended and that the locus of post-Miocene volcanism in the Crater Flat Basin lies in the south and southwestern portion of the basin, volcanic source zones defined in the PVHA and centered in the southwestern Crater Flat Basin are consistent with the tectonic history and structural features of the Crater Flat Basin structural domain (CRWMS M&O 2000b, Section 6.4.2).

The spatial distribution of the volcanic hazard defined by the PVHA expert interpretations and recalculated to account for the repository design defined by EDA II, Design B (CRWMS M&O 1999a), is presented in Figure 3-2. Part (a) shows a map of the frequency of occurrence of volcanic events as defined above. The contours on the map depict the expected frequency of volcanic events occurring at that location. The potential repository, indicated by the white rectangle in the center of the maps, lies outside the region of highest event frequency (Crater Flat region to the west), but near enough to possibly be affected by dikes generated within this region. The estimated rate of volcanic events in the location of the potential repository is lower than that in Crater Flat, but is higher than regions to the east. Part (b) shows a map of the contributions to the frequency of intersecting the potential repository by a basalt dike. The contours on map (b) depict the frequency of volcanic events occurring at specific locations which produce dikes that intersect the potential repository footprint. There is a distinct contribution to the frequency of dike intersection from potential volcanic events in Crater Flat. There is also a distinct contribution from potential volcanic events in the immediate vicinity of the potential repository. Note that the maps represent the mean results averaged over ten experts and over each expert's logic tree (CRWMS M&O 1996, Appendix E). Section 3.1.1.2 contains summary frequencies of disruptive volcanic events including the 5th and 95th percentiles and the means.

The event rate in the Yucca Mountain region depends on the number of events estimated to have occurred in particular time periods. The only factor that could significantly change PVHA estimates of the number of events and the event rate would be evidence not considered during the PVHA of a significant number of previously unidentified buried volcanic centers or intrusions. Section 6.3.1.6 of the AMR summarizes new data regarding aeromagnetic anomalies that could potentially change the assessment of the number of volcanic events by the PVHA experts (Earthfield Technology 1995; Connor et al. 1997; Magsino et al. 1998). The Earthfield Technology (1995) results were based on the merging of three aeromagnetic data sets, the Timber Mountain, Lathrop Wells, and Yucca Mountain surveys. The Timber Mountain survey portion of the Earthfield technology data set has been shown to be incomplete and mislocated (Feighner and Majer 1996, p. 1). For this reason, further analysis of the anomalies as presented by Earthfield Technology (1995, Appendix II), that lie within the Timber Mountain survey, is not warranted. The six anomalies located within 5 km of the potential repository site (the Yucca Mountain survey) are associated with mapped faults and are probably due to faulting of the Topopah Spring Tuff, which is one of the major magnetic anomaly producing formations in the Yucca Mountain region (Feighner and Majer 1996, pp. 1 to 3; Reamer 1999, p. 32). New ground magnetic surveys presented in Connor et al. (1997) and Magsino et al. (1998) provide



Source: CRWMS M&O 2000b, Figure 17

NOTES: White Rectangle in Center of Maps Represents Potential Repository Footprint; Grid is Universal Transverse Mercator (UTM).

Figure 3-2. Spatial Distribution of Volcanic Hazard Defined by the PVHA Expert Panel: (a) Map of Expected Volcanic Event Frequency and (b) Map of Spatial Disaggregation of Expected Intersection Frequency the most reliable and detailed data available for magnetic anomalies in the Yucca Mountain region. Sensitivity studies were conducted based on Connor et al. (1997) that assess the potential impact of increased event counts in Amargosa Valley and Crater Flat. The mean value for the number of buried volcanic centers was increased from the original PVHA value of 4.7 events to 6.1 events, resulting in an increase in the mean annual frequency of intersection of a dike with the repository of 4 percent (CRWMS M&O 2000b, Section 6.3.1.6). Significantly, the four anomalies east of Yucca Mountain (Magsino et al. 1998, Figure 1-1) show no evidence of buried volcanic centers and provide confirmatory evidence that the volcanic source zones specified by the experts to the south and west of Yucca Mountain are a valid representation of the spatial distribution of post-Miocene volcanism in the Yucca Mountain region (CRWMS M&O 2000b, Section 6.3.1.6).

In order to evaluate the consequences of a volcanic event contacting the repository, information is needed on the length and orientation of the intersecting dike and the probability that an eruptive center, the vent above the conduit feeding an erupting volcano, forms over the repository footprint. Section 6.5 of the AMR develops these assessments. The calculation of conditional distributions for the number of eruptive centers within the repository footprint requires an assessment of the number of eruptive centers associated with a volcanic event and the spatial distribution for eruptive centers along the length of the dike. The PVHA experts were not asked to make this assessment as part of their characterization of the volcanic hazard. However, the number of eruptive centers associated with a volcanic event can be derived from the PVHA experts' evaluation of the number of volcanic events that have occurred in the Quaternary using the following assumptions.

- The mapped Quaternary volcanoes in the Yucca Mountain region are representative of the type being characterized for calculation of the consequences of an eruptive event through the repository. In particular, each volcano consists of at least one vent where a subsurface conduit intersects the earth's surface.
- Each hypothetical volcanic event for which the associated dike intersects the repository has at least one eruptive center located somewhere along the length of the dike.
- The location of an eruptive center along the length of a dike or dike segment is defined by a uniform probability distribution.

The approach used in the AMR to calculate the probability of a volcanic event producing one or more eruptive centers within the repository is outlined in Table 3-3. The length of intersection within the repository footprint compared to the total length of the dike, the number of eruptive centers per volcanic event, and the spatial distribution of eruptive centers along the length of the dike provides the bases for assessing the likelihood that one or more eruptive centers will occur within the repository footprint. The assumptions regarding the number or eruptive centers per volcanic event and the spatial distribution of eruptive centers along the length of the dike can be applied in alternative ways. In keeping with the concept of uncertainty characterization employed in the PVHA, these alternatives were used to develop alternative assessments of the conditional distribution for the number of eruptive centers within the repository footprint. These are then combined, using relative weights assigned to each, to produce a composite assessment.

Table 3-3. Approach Used To Assess the Annual Frequency of a Volcanic Event Producing One or More Eruptive Centers within the Repository for TSPA-SR

Calculate the Frequency of Intersection of the Repository Footprint by a Dike	
1	PVHA formulation (CRWMS M&O 1996, Section 3).
2	Calculated for both the EDA II and SRSL 70,000 MTU no backfill repository footprint.
Calculate the Conditional Probability that an Intersecting Dike Will Produce a Specific Value of Length and Azimuth within the Repository	
1	Break down (disaggregate) the total frequency of intersection into frequencies for specific values of intersecting dike length, dike azimuth, and intersection length increments.
2	The sum of the numbers in all length-azimuth bins equals the frequency of intersection.
3	The values in each bin divided by the frequency of intersection provide a conditional distribution for length and azimuth given an intersection occurs.
Calculate the Conditional Distribution for the Number of Eruptive Centers that Occur within the Repository Footprint Given That There Is an Intersection by a Dike Associated with a Volcanic Event	
1	Derive empirical distributions for the number of eruptive centers per volcanic event based on the PVHA experts' assessments of the number of volcanic events represented by the observed eruptive centers in the Yucca Mountain region and characteristics of Quaternary volcanoes in the PMR (and assumptions described above).
2	Assess the possible correlation between the number of eruptive centers and dike length.
3	Assess the spatial distribution of eruptive centers along the length of the dike.
4	Use a range of possible assessments to incorporate uncertainties in these parameters into the analysis. Five alternative approaches developed to implement assumptions in order to span the range of available approaches.
5	Run an additional calculation that incorporates an alternative model in which the presence of the repository openings results in the occurrence of at least one eruptive center given an intersection.

Source: Compiled from information in CRWMS M&O 2000b, Section 6.5

Weights assigned to each model are derived by separately examining the three issues addressed by the alternative approaches. The first five alternative approaches are all based on the assumption that the presence of the repository openings has no effect on the probability of occurrence of an eruptive center within the repository footprint. A sixth alternative assumption, that the presence of the repository openings induces the occurrence of at least one eruptive center within the footprint, was included as an equally weighted alternative in developing the final assessment of the conditional probability distributions for the number of eruptive centers within the repository footprint.

3.1.1.2 Conclusions of AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*

Results of the PVHA (CRWMS M&O 1996, Section 4) have been recalculated to account for the EDA II design (Table 3-4a) and for the current repository footprint, SRSL, (Table 3-4b) and extended to include the probability of an eruption within the repository footprint, conditional on a dike intersection. A conceptual framework for the probability calculations, based on PVHA outputs and subsequent studies, accounts for deep (mantle) and shallow (structural control) processes that influence volcanic event distribution in the Yucca Mountain region. The framework presented in the AMR emphasizes the close correlation between the distribution of volcanic events and areas of crustal extension and faulting in the Yucca Mountain region, and within this context, the appropriateness of spatial distribution models defined in the PVHA. It also emphasizes the appropriate selection of parameter distributions that affect probability models and provides support for comparison of alternative conceptual frameworks and parameter selection, within the framework of the volcanic history of the Yucca Mountain region. Alternative models presented by the NRC (Reamer 1999, Sections 4.1.6.3.2, 4.1.6.3.3) that result in higher eruption probabilities (10^{-7}) than those presented here (EDA II: 7.7×10^{-9}; and SRSL: 1.3×10^{-8}) employ input parameters that represent extreme values (e.g., event length) or assume specific geologic controls (i.e., crustal density) on spatial distribution. Spatial density models weighted by crustal density result in higher event frequencies at the potential repository site, while the same models weighted by an alternative geologic control, such as cumulative crustal extension across the Crater Flat structural domain, would likely lead to decreased event frequencies at the site. The NRC states that the highest value (10^{-7} per year) in their range of calculated probability values (10^{-8} to 10^{-7} per year) cannot be considered more or less likely than any other value they have calculated using alternative probability models (Reamer 1999, p. 61). The analysis in the AMR suggests that the choice of input parameters used by the NRC compared to those used in the PVHA places the highest NRC probability value at the extreme upper tail of a probability distribution.

Table 3-4a. Summary Frequencies of Intersection of Potential Repository by a Dike and Occurrence of One or More Eruptive Centers within Repository Footprint for EDA II Design with Backfill

Potential Repository Footprint (EDA II)	Hazard Level	Annual Frequency of Intersection of Potential Repository by a Dike	Weighted Conditional Probability of at Least One Eruptive Center	Annual Frequency of Occurrence of One or More Eruptive Centers within Potential Repository
Primary Block	5th percentile	6.6×10^{-10}	0.42	2.8×10^{-10}
	Mean	1.4×10^{-8}	0.47	6.7×10^{-9}
	95th percentile	4.7×10^{-8}	0.47	2.2×10^{-8}
Primary + Contingency Blocks	5th percentile	7.6×10^{-10}	0.44	3.3×10^{-10}
	Mean	1.6×10^{-8}	0.50	7.7×10^{-9}
	95th percentile	5.0×10^{-8}	0.49	2.5×10^{-8}

Source: CRWMS M&O 2000b, Table 13; CRWMS M&O 1999a

Table 3-4b. Summary Frequencies of Intersection of Potential Repository by a Dike and Occurrence of One or More Eruptive Centers within Repository Footprint for SRSL 70,000 MTU Design with No Backfill

Potential Repository Footprint (70,000 MTU Layout)	Hazard Level	Annual Frequency of Intersection of Potential Repository by a Dike	Final Composite Conditional Probability of at Least One Eruptive Center	Annual Frequency of Occurrence of One or More Eruptive Centers within Potential Repository
Primary Block	5th percentile	6.8×10^{-10}	0.73	4.9×10^{-10}
	Mean	1.5×10^{-8}	0.77	1.1×10^{-8}
	95th percentile	4.8×10^{-8}	0.76	3.6×10^{-8}
Primary + Contingency Blocks	5th percentile	7.9×10^{-10}	0.74	5.9×10^{-10}
	Mean	1.6×10^{-8}	0.77	1.3×10^{-8}
	95th percentile	5.2×10^{-8}	0.76	4.0×10^{-8}

Source: CRWMS M&O 2000b, Table 13a; CRWMS M&O 2000z

The annual frequency of intersection of the repository footprint by a dike associated with a volcanic event, and the annual frequency of a volcanic event producing one or more eruptive centers within the repository, have been recalculated based on the EDA II design (Table 3-4a) and on the current repository footprint, SRSL, (Table 3-4b). The values listed in Table 3-4a and Table 3-4b are the weighted combination of the alternative models for eruptive centers.

Conditional distributions for the length and azimuth of the intersecting dike and the number of eruptive centers occurring within the repository footprint are developed for the six values of frequency of intersection in Table 3-4a and Table 3-4b. These distributions are very similar for all six conditions. The alternative models for specifying the number and spatial distribution for eruptive centers associated with a volcanic event have relatively small effects on the conditional distribution for the number of eruptive centers occurring within the repository footprint.

The annual frequencies of intersection of the repository footprint by a dike associated with a volcanic event are utilized directly within the TSPA-SR model. This model restricts the length of cumulative distribution functions to 100 values. The values presented in Tables 3-4a and 3-4b represent full distributions which are then binned together to generate a cumulative distribution function of less than 100 points for the primary and contingency block values.

3.1.2 Characterize Eruptive Processes at Yucca Mountain, Nevada

The AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) presents information about basaltic volcanic systems and the parameters that could be used to model their behavior. This information is used to develop parameter value distributions appropriate for analysis of the effects of volcanic eruptions through a potential repository at Yucca Mountain. Table 3-5 summarizes key points of the AMR. The discussion following the table provides selected details supporting the table. For more detail and supporting references, see the AMR.

As shown in Table 3-5, based on literature research and use of some YMP data, this AMR describes and constrains the following broad topics relevant to basaltic volcanism in the Yucca Mountain region:

- The geometry of volcanic feeder systems, which are of primary importance in predicting how much of a potential repository would be affected by an eruption.
- The physical and chemical properties of the magmas, which influence both eruptive styles and mechanisms for interaction with radioactive WPs.
- Eruptive processes including the ascent velocity of magma at depth, the onset of bubble nucleation and growth in the rising magmas, magma fragmentation, and velocity of the resulting gas-particle mixture.
- The duration of eruptions, their power output, and mass discharge rates.
- Geologic constraints regarding the interaction between magma and WPs.
- The bulk grain size produced by relevant explosive eruptions, and grain shapes.

Table 3-5. Summary of Key Points for Disruptive Events AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada*

Assumptions	
1	Future volcanic activity over the 10,000 year performance period will be the same type as Quaternary basaltic eruptions in the Yucca Mountain region.
2	Lathrop Wells is an analog that is emphasized.
3	New volcanoes can be expected to display a combination of scoria cone(s), spatter cone(s) and lava cone(s) at the surface.
4	Both intrusive and extrusive events will contain one or more dikes in the subsurface.
Inputs	
1	General information and values from review of published literature: analog data; conduit size; dike system geometry; magma properties; dynamics of ascending magma; eruption volume, duration and power; grain sizes of explosive basaltic eruptions; and bulk density of pyroclastic fallout deposits.
2	Major element composition of Lathrop Wells products (from YMP data).
3	Quantities of xenoliths erupted from volcanoes similar to Yucca Mountain region volcanoes (from YMP and non-YMP data).
Outputs	
1	Conduit diameter.
2	Dike width.
3	Number of dikes associated with formation of an intrusion.
4	Magma chemistry (from Lathrop Wells).
5	Magma water content.
6	Volcanic gas composition.
7	Magmatic temperatures, viscosities and densities.
8	Magma ascent rate below vesiculation (bubble formation) depth.
9	Volatile exsolution depths.
10	Fragmentation depths.
11	Velocity as a function of depth – Estimated using a combination of published results and estimates that provide simple functions.
12	Eruption duration and volume.
13	Mean and standard deviation for magmatic particle size erupted during violent strombolian phases.
14	Clast characteristics. Shape factor for ASHPLUME .
15	Density of erupted particles.
16	Fallout deposit density.
Overview of Analysis Method	
1	Analyze literature for collection of information to produce parameter value distributions.
2	Synthesize literature to produce concepts of processes.
AMRs or Other Analyses Receiving Outputs	
1	*Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k).
2	*Dike Propagation Near Drifts* (CRWMS M&O 2000e).
3	*Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l).
Concepts Developed or Processes Constrained	
1	Geometry of volcanic feeder systems.
2	Physical and chemical properties of basaltic magmas.
3	Eruptive processes (including: magma ascent velocity, fragmentation and velocity of gas-particle mixture).
4	Eruption duration, power output and mass discharge rates.
5	Geologic constraints for interaction of magma and WPs.
6	Bulk grain size and grain shapes produced by explosive eruptions.

Source: CRWMS M&O 2000a

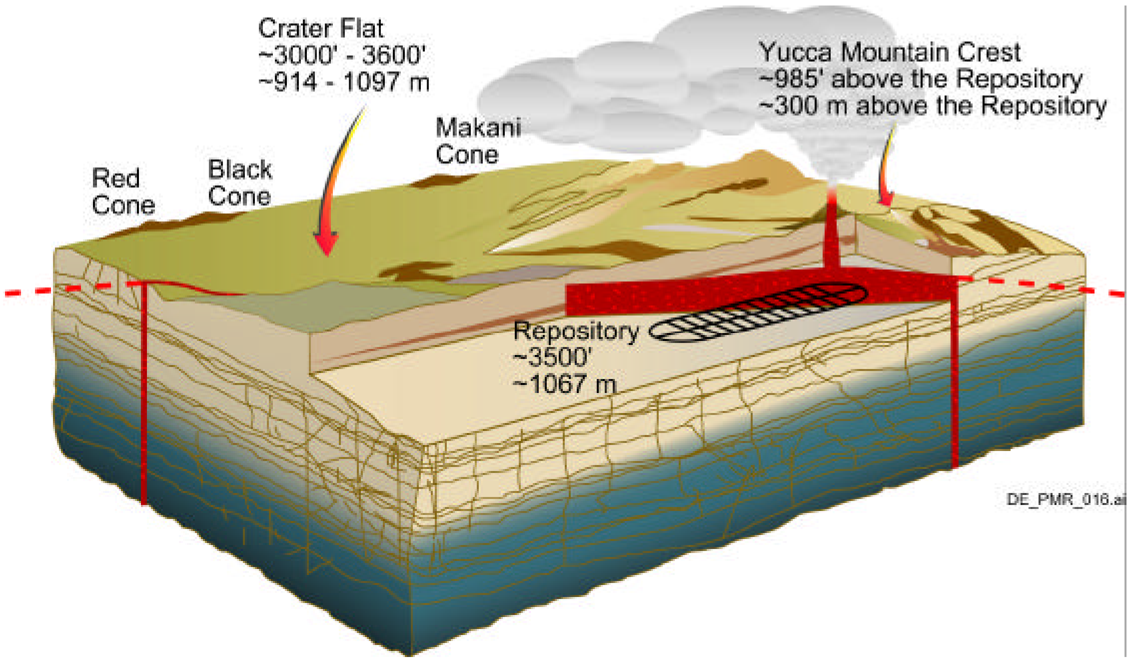
While some YMP-derived information was used as input to the AMR, most of the input was taken from a review of the published literature. As a result, the AMR relied heavily on values and concepts that were developed for volcanoes that are analogous in some way to those in the Yucca Mountain region. Inputs that originated with YMP included the major element composition of products of the Lathrop Wells volcano and the quantities of xenoliths erupted from volcanoes that shared some eruptive characteristics with Yucca Mountain region volcanoes. The xenolith data were originally collected to constrain the amount of waste that could be ejected if a volcano penetrated the potential repository.

Inputs from the published literature included values, or inferences, on volcanic conduit size; dike system geometry; volatile contents, material properties, and water saturation pressures of basaltic magmas; relationships describing the dynamics of ascending magmas; volumes, durations, and power outputs of historical scoria cone-forming eruptions; bulk grain sizes of explosive basaltic eruptions; and estimates of the *in situ* bulk density of pyroclastic fallout deposits.

Analyses in the AMR are based on the assumption that a plausible future eruption during the postclosure performance period would be of the same character as Quaternary basaltic eruptions in the Yucca Mountain region. Eruptive styles and magmatic composition recorded at the Lathrop Wells volcano, the most recent in the region, are emphasized. This implies that a new volcano will contain some combination of scoria cone, spatter cones and lava cones on the surface, and one or more dikes in the subsurface. There are several additional assumptions related to specific topics covered in the AMR, mainly focusing on the use of data from a variety of analog volcanoes and simplifications that are necessary for the theoretical analysis of magma ascent and eruption dynamics. Figure 3-3 shows a conceptualization of a stylized "plausible future eruption" in which a dike with a volcano occurs and intersects the repository.

The following specific parameter distributions resulted from the AMR:

- **Conduit Diameter**–Log normal distribution, minimum diameter equal to dike width, median diameter equal to 50 m, maximum value 150 m.
- **Dike Width**–Log normal distribution, minimum of 0.5 m, mean of 1.5 m, 95th percentile value of 4.5 m.
- **Number of Dikes Associated with Formation of a New Volcano**–Log normal distribution with minimum of 1, mean of 3, 95th percentile value of 10.
- **Magma Chemistry**–Mean Lathrop Wells composition.
- **Water Content of Magmas**–Zero probability of 0 weight percent increasing linearly to 1 weight percent, uniform distribution between 1 and 3 weight percent, zero probability of 4 weight percent with linear distribution between 3 and 4 weight percent.
- **Gas Composition**–Derived from a suite of active volcanoes.



NOTE: Elevations for the repository, Yucca Mountain crest and Crater Flat are referenced to mean sea level.

Figure 3-3. Volcanic Eruption Release Scenario Showing Yucca Mountain, Crater Flat, and Quaternary Cinder Cones

- **Magmatic Temperatures, Viscosities, and Densities**–Calculated from theoretical relations; liquidus temperature ranges from 1046 to 1169°C, viscosity ranges from 1.957 to 2.678 (log poise units), density ranges from 2474 to 2663 kg/m^3.

- **Magma Ascent Rate Below Vesiculation Depth**–From published equation of the AMR.

- **Volatile Exsolution Depths**–Range from about 9 km to zero depth for water contents between 0 and 4 weight percent.

- **Fragmentation Depths**–Range from 0 to 900 m (approximately) for water contents between 0 and 4 weight percent.

- **Velocity as a Function of Depth**–Estimated using a combination of published results and estimates that provides simple functions.

- **Eruption Duration**–For formation of an entire volcano, a log normal distribution with a minimum of one day, a mean of 30 days, and a maximum 15 years. Duration and volume of individual explosive phases during formation of a new volcano should be a probability distribution function with a cutoff so that sampled volumes or the sums of sampled volumes do not exceed the sampled volume of the whole volcano.

- **Mean Particle Size Erupted during Violent Strombolian Phases**–Log triangular distribution with a minimum of 0.01 mm, a mode of 0.1 mm, and a maximum of 1.0 mm.

- **Standard Deviation of Particle Size Distribution for a Given Mean**–Uniform distribution between 1 to 3 phi ($-\log_2$ units, negative log base 2).

- **Clast Characteristics**–Shape factor of 0.5.

- **Density of Erupted Particles**–For particle diameters less than or equal to 0.01 mm, density is 0.8 of the magma density. For particles greater than 10 mm, density is 0.4 of the magma density. For particles between 0.01 and 10 mm, density should decrease linearly with increasing diameter.

- **Density of Ash Deposit**–There are two possible ways of treating deposit density in TSPA-SR calculations: (1) Simply use 1000 kg/m^3 or (2) sample from a normal distribution of deposit densities ranging from 300 to 1500 kg/m^3, with a mean of 1000 kg/m^3 (for TSPA-SR, method 1 is used).

Within the framework of the Disruptive Events PMR group of analyses, the AMR provided input for three other AMRs: *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k), *Dike Propagation Near Drifts* (CRWMS M&O 2000e), and *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l). Some parameters developed by these AMRs were developed for use directly in downstream calculations (e.g., using the ASHPLUME atmospheric dispersal code in the consequence modeling AMR) and some were used directly in TSPA-SR.

3.1.3 Dike Propagation Near Drifts

The purpose of the disruptive events AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) was to develop analyses for the interactions of a hypothetical igneous dike with a repository drift or tunnel and with the drift contents. The preliminary analyses were needed to support evaluation of the consequences of an intrusive igneous event and to provide a basis for addressing some of the issues expressed in the IRSR on igneous activity (Reamer 1999). This AMR developed conceptual models for interactions of a hypothetical dike with a repository drift using the EDA II design option with drip shields and backfill (CRWMS M&O 1999a). This AMR also developed the same kinds of conceptual models for the SRSL design (CRWMS M&O 2000z) that included drip shields, no backfill, and a footprint that was shifted about 0.5 km north of the footprint used for the EDA II design. The shifting of the footprint did not impact this analysis. The underlying analytical approach and general concepts under which the results were derived remain the same for both analyses, and so, apply to both sets of results. Results for the no backfill design will be designated as such in the following discussion.

Table 3-6 summarizes key points of the AMR. The entries in Table 3-6 generally apply to both the EDA II (with backfill) and the SRSL (no backfill) designs. Those entries which apply to only one design are annotated appropriately. The discussion following the table provides selected details supporting the table. For more detail and supporting references see the AMR.

This analysis addresses a long-standing problem in understanding the nature of possible volcanic disruption of a drift, or set of drifts, in a repository. The scope of analysis for the AMR was to conceptualize the problems and to provide bounding concepts and parameter values from literature research for some of the processes involved.

Table 3-6. Summary of Key Points for Disruptive Events AMR *Dike Propagation Near Drifts*

Assumptions	
1	A real gas is supplied to the drift by the dike and as the gas flows down the drift: no axial temperature gradient; adiabatic expansion ignored; heat carried into rock by gas ignored; no gas/rock chemical reactions; components of EBS (including backfill) irrelevant to gas flow.
2	Magma phase changes are constrained according to literature cited in the AMR; drift wall temperature in the presence of solidified, chilled magma ~600°C.
3	Representative WP weighs 42 metric tons and contains 9.05 MTU (CRWMS M&O 2000x).
Inputs	
1	General information and literature values: basalt thermal conductivity; latent heat of fusion; specific heat; magma fusion temperature, density; gases exsolved from magma and gas properties.
2	Drift radius.
3	WP spacing and characteristics including: weight, skirt design; and, for the no backfill design (SRSL), lid diameter and thickness.
4	Drip shield general characteristics and placement.
5	Backfilled and open (no backfill) emplacement drifts and mains design options.
Outputs	
1	Estimates of sizes of effects during interaction of magma from a dike and the engineered components inside the emplacement drifts, for backfill and open drift (no backfill) design options, including reasonable bounds on: a) Temperature changes to WP from magma exposure. b) Gas flow available during magmatic intrusion. c) WP movement during magmatic intrusion. d) Backfill movement during magmatic intrusion. e) Mechanics of magma/drift interaction during intrusion. f) Shock propagation and magma flow down drift (no backfill design).
2	Number of WPs most affected (ruptured with contents available for removal) by magmatic environment immediately on either side of a dike is 3 or 4 on either side of the dike (with or without backfill).
Overview of Analysis Method	
1	Analyze literature.
2	Synthesize literature data to produce concepts of processes.
3	Perform stylized calculations for temperature changes, gas flow, and WP movement.
AMRs or Other Analyses Receiving Outputs	
	Number of Waste Packages Hit by Igneous Intrusion (CRWMS M&O 2000k).
Concepts Developed or Processes Constrained	
1	Dike propagation behavior in the thermally altered stress region surrounding the repository. Dikes may be deviated by altered stress field.
2	Flow of magma down drifts is limited to a few WP lengths by plugging from crumpled drip shields and displaced backfill.
3	Flow of magma down drifts without backfill, possibly as pyroclastic flow, may extend the length of a drift unless impeded by plugging from crumpled drip shields and disrupted ground support (no backfill design).
4	Shock propagation and pressure pulse down drifts and mains without backfill may reach all connected drifts whether those drifts are intersected by the dike or not (no backfill design).
5	Solidification time and temperature for chilling magma constrained.
6	Cooling time for drift filled with solid pyroclasts constrained.
7	Gas flow down an idealized drift.
8	Conceptual models for characteristics of the magmatic environment for three zones for drifts intersected by a dike (no backfill design).
9	Conceptual models for potential WP damage for WPs disrupted by the magmatic environment, including shock wave and pressure pulse, for three zones (no backfill design).

Source: CRWMS M&O 2000e

Conceptual models developed in the AMR (as presented in the AMR conclusion section) include:

1. Waste package temperature due to flow of magma and pyroclasts down a blind (closed end) drift.

2. Steady-state gas flow down a blind (closed end) drift to interact with WPs.

3. Physical interactions of the pressure pulse from the dike in displacing WPs and drift contents.

4. Qualitatively, the interaction of the self-generated crack leading the dike with the stress-altered region around the drift.

5. Physical interaction of a pressure pulse with the drift contents for the zone in an intersected drift not immediately adjacent to the dike, including conceptualization of damage to WPs in this zone.

The temperatures of WPs when engulfed in magma (Number 1 above) were analyzed to improve the conceptual model of behavior of WPs in the magmatic environment over that for the TSPA-VA. Comparison of WP temperature information to results of the calculation *Waste Package Behavior in Magma* (CRWMS M&O 1999b), performed within the EBS PMR group of analyses and calculations, indicates the WPs would be very near failure condition in the magmatic environment if temperature and internal pressure due to fuel rod rupture were considered. Gas flow down drifts (Number 2 above) was examined to provide information on the chemical environment that could be expected to affect WPs due to gas flow down drifts. Development of a pressure pulse in the drift at the point when the dike made its initial contact (Number 3 above) was examined to provide a conceptual model for this process that was lacking in TSPA-VA analyses. Stress alteration around the drifts (Number 4 above) caused by the drift excavation and the thermal period from waste emplacement is important because dikes (in the shallow crust) propagate in a direction that is perpendicular to the direction of the least principal stress. The thermally and mechanically altered stress zone around the repository out for several hundred meters shifts the least principal stress direction from the normal horizontal orientation to a vertical orientation for about 2000 years. Figure 3-4 is a conceptualization of the altered stress field surrounding the potential repository. For the no backfill design (SRSL) a conceptual model was required to evaluate the damage that could result from a pressure pulse caused by dike intersection with open drifts (Number 5 above). The AMR conceptualized the damage in this zone as being endcap weld failure.

The AMR supports addressing consequence acceptance criteria 3 and 4 in the Igneous Activity IRSR and the NRC alternative conceptual models described in the discussion of the acceptance criteria in the IRSR (Reamer 1999). Chapter 4 of this Disruptive Events PMR describes how the disruptive events analyses, including the dike propagation AMR, address the acceptance criteria. Alternative models are discussed in Chapter 4.

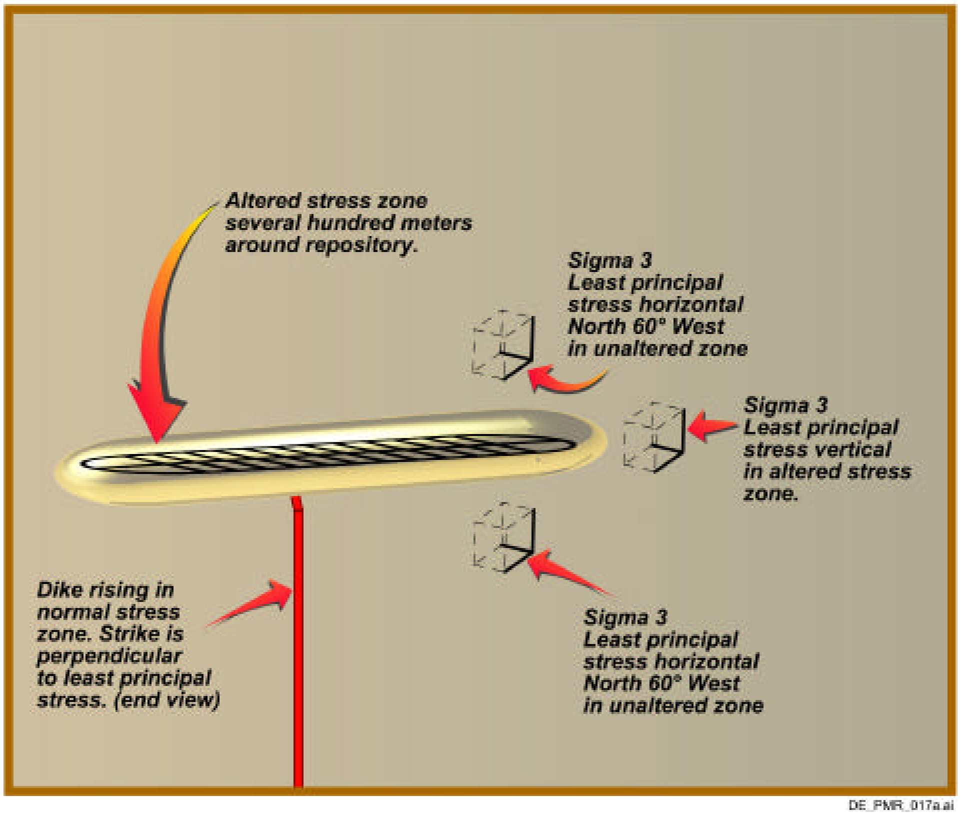


Figure 3-4. Conceptualization of Mechanically and Thermally Altered Stress Field Surrounding Potential Repository

Based on these analyses, the following conditions are physically possible and not excluded by data relevant to Yucca Mountain or the repository (CRWMS M&O 2000e, Section 7). These conditions generally apply to both the EDA II (with backfill) and the SRSL (no backfill) designs. Those which apply to only one design are annotated appropriately.

1. The thermally altered stress state of the mountain may cause propagating dikes to deviate from the direction dictated by the undisturbed least principal stress direction for about 2000 years.

2. Disruption of WPs caused by flow from the dike extends down the drift from the dike edge to 3 or possibly 4 WPs. (This determination is based on the interaction of the pressure pulse with the WPs and the resulting translation of the packages resulting from the pressure pulse. Four packages are damaged if the first package affected slides rigidly off the emplacement pallet.)

3. For the case of backfilled emplacement drifts (EDA II), magma flow down the drift is limited to a few WP lengths (11 to 22 m) by plugging from the crumpled drip shield and displaced backfill.

4. For the case of open emplacement drifts (no backfill design, SRSL) magma flow (possibly as pyroclasts) may extend the length of the drift unless impeded by plugging from crumpled drip shields and disrupted ground support.

5. For the potential case of open emplacement drifts and mains, shock propagation and pressure pulse may reach all connected drifts whether they are intersected by the dike or not. If emplacement drifts are open and mains are backfilled, the shock propagation and pressure pulse influence is limited to emplacement drifts intersected by a dike.

6. Solidification of a chilling magma plug with an initial temperature of 1100°C occurs in about 70 to 82 days. Cooling time for a drift filled with solid pyroclasts (initial temperature 1100°C, final temperature 125°C) takes on the order of a decade.

7. Gas flow down an idealized drift is about 3.5×10^2 to 3.5×10^3 m^3/sec.

Estimates of the number of WPs at risk from magma from an igneous dike and the nature of that risk provided inputs for one disruptive events AMR and one calculation, *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) and *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k).

3.1.4 Number of Waste Packages Hit by Igneous Intrusion

The calculation *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k) used inputs from several disruptive events AMRs to calculate the number of WPs hit (meaning affected) by a volcanic dike intrusion and a volcanic conduit intersecting the potential repository. This calculation was conducted using EDA II which included drip shields and backfill (CRWMS M&O 1999a) and for the SRSL design which includes drip shields, no backfill, and a footprint that was shifted about 0.5 km further north (CRWMS M&O 2000z). Another feature of the no backfill design (SRSL) was a realignment of the repository drifts with regard to the orientation in the EDA II design, and that data was also used in the calculation. The calculation approach for the igneous intrusion scenario was different for the backfill and the no backfill cases. The calculation for the case without backfill used the areal dimensions of the drift design elements (i.e., rock pillars and drift openings) versus a linear intersection approach (i.e., spacing between elements), for the case with backfill, to calculate the number of WPs hit.

Input information was used to calculate the number of WPs that would be hit, and assumed engulfed by magma and/or pyroclastic flow during both extrusive and intrusive volcanic eruptions through a potential repository at Yucca Mountain. The PVHA report (CRWMS M&O 1996) provides the framework for three AMRs that provide input for this calculation. These AMRs include: *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b); *Dike Propagation Near Drifts* (CRWMS M&O 2000e); and *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a). The objectives of this calculation were to determine the number of WPs contacted by igneous intrusion under two different scenarios:

- The volcanic eruption scenario calculation addressed the number of WPs damaged by a volcanic eruption. This number reflects the calculated number of WPs that were contained within an eruptive conduit of a specified diameter, given that a dike has intersected the drift and that the conduit is located at a drift.

- The igneous intrusion groundwater transport scenario addressed the number of WPs damaged by an igneous intrusion (dike) that intersected the repository but did not necessarily result in an eruption. This number reflects the calculated number of WPs in the drifts that have been damaged *in situ* by magma, given that a dike has intersected the drifts.

For the igneous intrusion groundwater transport scenario, described in the second bullet above, the disruptive events AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) described different damage scenarios for the designs with and without backfill. For the design with backfill the number of WPs hit by the dike intrusion was designated as only those immediately on either side of the dike. For the design without backfill the conceptual model for WPs damaged by a dike intrusion included three zones of damage, numbered 1 through 3, and the calculation used the design input to determine the number of packages in each of these zones. Zone 1 includes the WPs immediately on either side of a dike intersection (3 or 4 WPs on each side [see Section 3.1.3 in this PMR]). It is assumed that 3 WPs on each side are damaged to the point that they provide no further protection for the waste (CRWMS M&O 2000l). The concept of this zone is the same whether backfill is present or not. This calculation for number of packages hit includes removal of one package directly at the point of the dike intersection. This brings the number of packages hit in Zone 1 to seven, the three on either side of the dike and the one at the point of intersection. Zone 2 includes the WPs in the part of the intersected drifts that is not immediately on either side of the dike. In this zone the damage to WPs results from the exsolution of volatiles from magma caused by dike intersection, and applies only to the no backfill case. The damage to WPs in this zone is endcap weld failure, removal of drip shields, and cladding failure. Zone 3 applies to the no backfill case and includes the WPs in drifts not intersected by a dike. Damage to WPs, drip shields, and cladding in Zone 3 is expected to be negligible.

Table 3-7 summarizes key points of the calculation. For more detail and supporting references, see the calculation (CRWMS M&O 2000k).

Table 3-7. Summary of Key Points for Disruptive Events Calculation *Number of Waste Packages Hit by Igneous Intrusion*

Assumptions	
1	Input from AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) for the distributions for dike properties and number of eruptive centers is appropriate for the primary and contingency blocks of the repository and is representative for igneous intrusive events in the Yucca Mountain region.
2	Inputs from AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) for the distributions for dike width and conduit diameter and input from *Maximum Number of Dikes in a Swarm* (CRWMS M&O 2000aa) are representative for igneous intrusive events in the Yucca Mountain region.
3	The point of intersection of a dike with the repository occurs at the widest part of the repository.

Table 3-7. Summary of Key Points for Disruptive Events Calculation *Number of Waste Packages Hit by Igneous Intrusion* (Continued)

4	The input from AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) for the distance magma will flow away from an intersecting dike and for designation of the location of 3 zones of damage for the no backfill repository design is considered as representative for igneous intrusive events in the Yucca Mountain region. For both designs this input defines a Zone 1 (15 m on each side of an intersecting dike) where the WPs are considered damaged to the point of providing no protection for the waste. For the no backfill design this input also defines a Zone 2 that includes the full length of an intersected drift beyond Zone 1 where WPs are assumed to experience variable degrees of damage caused by high pressures and temperatures associated with exsolution of volatiles from magma.
5	All dikes in a swarm are assumed to have the same length and width.
6	When multiple dikes intersect a drift, the dike spacing is about 30 meters. This assumption is a simplification and, together with Assumption 4, maximizes the number of WPs hit by magma flowing along the drift.
7	When one conduit (< 90 meters in diameter) intersects a drift, that conduit is centered within that drift, and all WPs within the conduit diameter are destroyed.
8	When the diameter of one conduit is greater than 90 m, the conduit is centered on a pillar and it intersects two drifts. The number of WPs affected in two adjacent drifts is maximized by this assumed conduit location.
9	When multiple conduits occur within the repository footprint, all conduits are coincident (centered) with drifts or centered on a pillar, depending on the conduit diameter (see assumption 8).
10	Only those WPs located partially or entirely within the area of the eruptive conduit contribute to the radionuclide source term for the volcanic eruption release scenario.
Inputs	
1	Repository layout (CRWMS M&O 2000z) including WP length, package spacing, drift orientation, drift spacing, drift diameter, and most likely dike lengths and directions inside the repository.
2	Distributions for dike length and azimuth angle.
3	Distribution for number of eruptive centers within the repository footprint.
4	Distributions for conduit diameter, dike width, and number of dikes in a swarm.
5	Distance magma will flow in a drift away from an intersecting dike.
Outputs	
1	For volcanic eruption scenario: a) Conduit diameter cumulative distribution function. b) Number of packages hit as a function of conduit diameter. c) Probabilities for number of conduits on a dike.
2	For igneous intrusion groundwater release scenario: a) Cumulative distribution function for number of packages hit in Zone 1 (corresponds to the total number of packages hit for a design with backfill). b) Cumulative distribution function for number of packages hit in Zone 1 + Zone 2.
Overview of Analysis Method	
	Input information was used in hand calculations which were facilitated by using accepted spreadsheet functions.
AMRs or Other Analyses Receiving Outputs	
	Igneous Consequence Modeling for TSPA-SR (CRWMS M&O 2000l).
Concepts Developed or Processes Constrained	
	Not applicable. Calculations do not develop this type of material.

Source: CRWMS M&O 2000k

The methodology for the calculation summarized in Table 3-7 involved the use of commercial spreadsheet applications to calculate probabilities and a cumulative distribution function for the parameters listed in the outputs section. For the volcanic eruption scenario, the cumulative distribution function for conduit diameter was sampled to determine the number of WPs hit for each conduit diameter. In addition, random sampling from the number of conduits on a dike cumulative distribution function was performed using a built-in commercial spreadsheet application to calculate multiple realizations for the probabilities of various numbers of conduits. For the igneous intrusion groundwater transport scenario, the cumulative distribution functions for dike width and number of dikes in a swarm were manually selected to exhaustively sample all dike width/number of dike combinations to develop cumulative distribution functions for number of WPs hit in Zone 1 and in Zones 1 and 2 combined for the design with no backfill. The development of the spreadsheets is discussed in the calculation (CRWMS M&O 2000k).

The volcanic eruption spreadsheets calculate the number of packages hit per conduit of a specified diameter and the probability of a specified number of conduits occurring for a range of conduit diameters. The conduit diameter distribution came from the AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) and the distribution for the number of conduits per event came from the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b).

The igneous intrusion groundwater transport spreadsheets calculate the number of packages contacted by magma immediately on either side of a dike intersecting a drift, and this calculation is the same for both designs. For the no backfill design the calculation assumes two zones of impact. Zone 1 includes an area that encompasses three WPs on each side of an intersecting dike (dike width plus about 30 m). All WPs in this zone are assumed to be damaged to the point that they provide no further protection for the waste, and their contents are immediately available for groundwater transport. The number of WPs in Zone 2 is calculated as the number of WPs in the drift minus the number of WPs in Zone 1. This calculation only provided information on the number of WPs in Zones 1 and 2. The concept of WP damage in the different zones is developed in the dike propagation AMR (CRWMS M&O 2000e) and the igneous consequences AMR (CRWMS M&O 2000l). For Zone 1 the maximum number of WPs severely damaged is 1,785 and for Zone 1 and 2 combined the maximum number is 11,184 (see CRWMS M&O 2000k for further details).

3.1.5 Igneous Consequence Modeling for TSPA-SR

The role of this AMR is a key one in the overall scheme of analysis for disruptive events related to volcanism, as discussed in Section 2.2 of this Disruptive Events PMR. This section contains a discussion of igneous consequence modeling taken from the AMR (CRWMS M&O 2000l). This section also contains a comparison of the TSPA-SR analysis for volcanism with the analysis performed for TSPA-VA.

The igneous consequence modeling AMR receives inputs from the AMRs summarized in Sections 3.1.1, 3.1.2, 3.1.3 and 3.1.4 of this PMR. Those inputs, taken together, provide the geologic characterization, parameters, and parameter values used to describe two disruptive events volcanism scenarios, volcanic eruptive release and igneous intrusion groundwater release. The igneous consequence modeling AMR analysis prepares parameter inputs taken from the other AMRs for use in PA modeling. The parameters and parameter values that characterize the volcanism scenarios are, to some extent, dependent on the potential repository design. An example is whether parameters are required that vary with regard to the presence or absence of backfill. The summary in this section of this PMR describes the general framework of the analysis under the igneous consequence AMR and provides a summary table with parameter categories and some representative values taken from the design case with backfill (EDA II).

The purpose of the igneous consequence modeling AMR was to develop credible, defendable, substantiated conceptual models for the consequences of igneous activity for the TSPA-SR. The analysis of igneous consequences for TSPA-SR represents an improvement over that of the TSPA-VA analysis by improving the quality and depth of scenarios and technical bases underlying the conceptual models. The AMR used data extracted from existing sources to design and support models for two scenarios: volcanic eruption release and igneous intrusion groundwater release. Volcanic eruptive release is described as an event that results in waste-containing ash being ejected from Yucca Mountain. Igneous intrusion groundwater release is described as an igneous event that reaches the repository level, impacts the WPs, and produces releases into the UZ from WPs damaged by igneous activity. Table 3-8 summarizes key points of the AMR. Because the igneous consequence AMR uses inputs from other disruptive events AMRs to develop conceptual models for TSPA-SR the table includes concepts from those AMRs as cited. The discussion following the table provides selected details supporting the table.

Table 3-8. Summary of Key Points for Disruptive Events AMR *Igneous Consequence Modeling for TSPA-SR*

Assumptions	
1	Climate change will not materially affect wind speed and direction, so use of current Yucca Mountain region data captures variability for future conditions.
2	Wind speed and direction data are uncorrelated parameters.
3	It is acceptable to combine wind speeds and directions into single distributions for each parameter regardless of the altitude from which data were collected.
4	All eruptions include a violent strombolian phase with fragmentation of the ascending magma into pyroclasts occurring below the repository horizon.
5	Any WP, drip shield, or other EBS component intercepted, partially or wholly, by an eruptive conduit is fully destroyed. All waste in destroyed packages is available for entrainment in eruption.
6	Any WP, drip shield, or other EBS component that is intercepted, partially or wholly, by an intrusive dike is damaged. The three WPs on either side of an intrusive dike are hit and damaged to the point of providing no protection for the waste.
7	During an eruptive event components of the EBS within the conduit, including WP and drip shield, provide no protection to the waste.
8	Waste from the WPs immediately on either side of a dike and at the point of dike intersection, a total of seven, (CRWMS M&O 2000k, 2000e), as described in assumption 6, is exposed, and all waste material in them is available for input to the UZ transport model dependent on solubility limits and availability of groundwater.
9	For estimation of waste particle diameters in eruptive environment all waste is unaltered commercial spent fuel.
Inputs	
1	Volcanic eruption event (ASHPLUME) inputs:
	a) Waste particle size distribution, CDF.

Table 3-8. Summary of Key Points for Disruptive Events AMR *Igneous Consequence Modeling for TSPA-SR* (Continued)

Inputs (Continued)

b) Maximum particle diameter for transport, 10cm.

c) Minimum height on eruption column considered in transport, 1m.

d) Air density 0.001117g/cm^3 and viscosity, 0.0001758 g/m-s.

e) Constant relating eddy diffusivity and particle fall time, 400 cm2/sec$^{5/2}$.

f) Incorporation ratio (incorporation of waste with ash particles), 0.3.

g) Ash parameters:

-Threshold limit on ash accumulation 1e –10; particle shape factor 0.5; settled density 1g/cm^3; particle densities at minimum/maximum particle sizes 2.08g/cm^3 to 1.04g/cm^3; minimum/maximum particle sizes for densities 0.01/cm ash to 1.0cm ash; mean particle diameters derived from a cumulative distribution function; mean particle size standard deviations derived from a cumulative distribution function; ash dispersion controlling constants derived from a cumulative distribution function.

h) Other eruption parameters:

-Eruptive volume, cumulative distribution function; event power, cumulative distribution function; initial eruption velocity, cumulative distribution function.

-Wind speed, cumulative distribution function and direction, probability density function.

-Conduit and number of packages hit parameters.

-Conduit diameters, cumulative distribution function; probability of >0 conduits, cumulative distribution function; number of packages hit per drift, cumulative distribution function; number of conduits intersecting waste, cumulative distribution function; percent of packages failing, 100%.

-Event probability, cumulative distribution function.

2 Igneous intrusion groundwater transport event inputs:

a) Event probability, cumulative distribution function.

b) Number of packages hit, cumulative distribution function.

c) Percent of WPs that are damaged.

Outputs

1 Documentation of support for TSPA parameter inputs from conceptual models and data.

2 Deliver appropriate documentation for conceptual models, data and parameters to appropriate Project databases.

3 Conceptual model parameter inputs delivered to TSPA-SR.

Overview of Analysis Method

1 Analyze two igneous events:

a) Hypothetical volcanic eruption that intersects repository.

b) Hypothetical igneous intrusion that results in exposing waste for groundwater transport away from the repository.

2 Use of spreadsheets to convert data received from several disruptive events AMRs to parameters in a suitable form for use in TSPA-SR models.

3 Pass through some results of disruptive events AMRs to TSPA-SR models without further analysis.

AMRs or Other Analyses Receiving Outputs

TSPA-SR model.

Concepts Developed or Processes Constrained

1 TSPA conceptual model for volcanic eruptive release.

2 TSPA conceptual model for igneous intrusion groundwater release.

Source: CRWMS M&O 2000l

Figure 2-16 (Section 2.2) shows the relationship between the major products of the other disruptive events AMRs that are relevant to this AMR. In that figure, the information flows, in a broad manner, from left to right. Outputs from all AMRs directly or indirectly support the TSPA-SR model that calculates the overall performance of the system. A discussion of the relationship between the igneous consequence modeling AMR, the other disruptive events volcanism AMRs, and AMRs from other groups is contained in Section 2.2.2 of this Disruptive Events PMR. The AMR treated data from other disruptive events AMRs in one of two ways: either data were passed to TSPA-SR unchanged, or Microsoft Excel spreadsheets were used to put the data received into a suitable format for use by TSPA-SR. Some TSPA-SR calculations receiving parameter values from the AMR also required input from other sources to complete certain models. For instance, calculations of radionuclide concentrations in groundwater resulting from igneous intrusion required input from the AMR and from waste dissolution models and UZ and SZ flow and transport models developed by other groups.

Objectives of the work were to develop and document conceptual models for the two scenarios analyzed, to deliver conceptual model parameter inputs to the TSPA-SR model in a form that was useable by the code, and to provide documentation for conceptual models, data, and parameters that were developed to the appropriate Project databases and records systems. Calculation of radionuclide releases and the resulting doses to the critical group were conducted within the TSPA-SR model as part of the overall analysis and were not part of the scope of the igneous consequence AMR. A major task of the AMR was preparation, through parameter development, of inputs to the ASHPLUME code that ran within the TSPA-SR calculation that modeled dispersal and fallout characteristics of ash and radionuclides for an eruptive plume from a volcano. Analyses performed under this AMR also prepared parameters for analysis of radionuclide release through the groundwater pathway from WPs compromised by intrusive igneous activity. At a summary level, calculation of this route of exposure involved input of an enhanced amount of radionuclides from the compromised WPs into the codes that modeled UZ and SZ flow and transport. For this scenario doses at the critical group location would occur after compromise of the WPs by intrusive activity because of groundwater travel times.

The conclusions of the AMR stated that the results provided the technical basis for the parameters that will be used by the TSPA-SR for modeling the two igneous activity scenarios analyzed. The AMR recommended that a code like ASHPLUME could be utilized within the TSPA-SR model for modeling potential volcanic eruptive events.

3.1.5.1 Confidence in the Conceptual Models

The models developed in the AMR consist of conceptual models for the response of the repository to igneous intrusion and volcanic eruption. Because the AMR does not document the computational implementation of the conceptual models it develops, quantitative validation cannot be provided by comparison of overall analysis results against data acquired from experiments or analog studies. Instead, confidence in the conceptual models is provided through the bases of the models and comparison with alternative conceptual models.

The volcanic eruption conceptual model is considered appropriate for use based on its consistency with available technical information and adequacy for its intended purpose. The conceptual model is derived directly from work published in the scientific literature and adopted by other workers, including the Center for Nuclear Waste Regulatory Analyses. Alternative conceptual models were considered during its selection, and it was determined to be the most suitable model available for the purpose of estimating the release and transport of ash and waste during a volcanic eruption at Yucca Mountain. The assumptions, parameter values and distributions used in the implementation of the conceptual model are also considered appropriate for the intended purposes.

The igneous intrusion groundwater transport conceptual model is also considered appropriate based on its conservatism with respect to overall performance. Similarly, the parameter values and distributions used in the implementation of this conceptual model have also been determined to be appropriate for the purposes of the analysis.

3.1.5.2 Comparison of TSPA-VA and TSPA-SR Assumptions/Methods for Volcanism Analysis

It can be seen from Figures 2-3 through 2-7 (Section 2.1.2.3) that several assumptions and methods were used for the TSPA-VA analysis that have been changed for TSPA-SR analysis. Table 3-9 contains a comparison of assumptions or methods used for the two PAs. Several changes in approach were the result of NRC comments on the TSPA-VA analysis (DOE 1998a, Section 4.4). The NRC comments of concern are listed in Section 3.3 of this Disruptive Events PMR.

Table 3-9. Comparison of Assumptions/Methods for Analysis of Volcanism for TSPA-VA and TSPA-SR

Topic of Assumption/Method	TSPA-VA Assumption/Method	TSPA-SR Assumption/Method
Repository Footprint	[1]Single emplacement block between Solitario Canyon and Ghost Dance Faults.	[2]EDA II, Design B.
Repository Design Components	[3]No drip shield or backfill evaluated for volcanism analysis. Drifts oriented east-west.	[2]Design for initial version of Disruptive Events AMRs = backfill + drip shield; ICN revision of Disruptive Events AMRs = drip shield, no backfill.
Fragmentation Depth	[4]Distribution developed. Occurs below repository depth. Analysis of WP damage and removal of waste from WP assumed ash particle impacts.	[5]May or may not occur below repository depth. Analysis of WP damage includes effects of liquid magma, ash particles and magmatic temperatures.
Waste Particle Size	[6]Range 0.01 cm to 1 cm. Mean 0.1 cm (100-10,000 microns).	[7]Range .0001cm to 0.05cm. Mode 0.002 cm (1-500 microns).
Magmatic Ash Particle Size	[6]Range 0.01 cm to 10 cm. Mode 1 cm.	[7]Range 0.001cm to 0.1cm. Mode 0.01 cm.
Eruptive Conduit Parameters	[8]Range 2 m to 120 m. Mean 50 m. Up to 2 conduits.	[7]Range 4.5 m to 150 m. Median 50 m. Up to 13 conduits.
Dike Parameters	[8]Dike width mean 1.5 m.	[9]Distribution calculated for dike azimuth and length of dikes within repository; Dike width distribution from AMR analysis; Dike swarms with mean of 3 dikes/swarm.

Table 3-9. Comparison of Assumptions/Methods for Analysis of Volcanism for TSPA-VA and TSPA-SR (Continued)

Topic of Assumption/Method	TSPA-VA Assumption/Method	TSPA-SR Assumption/Method
WP Performance	[10]WPs may survive ash particle effects during direct release (20% endure). WPs assumed compromised completely and contents available for transport for enhanced release scenario. WP durability was linked to thinning of WP layers by corrosion over time.	[11]Any WPs contacted directly by dike intersection during igneous intrusion groundwater release (TSPA-VA indirect release) or which are within a conduit during volcanic eruption release (TSPA-VA direct release) are assumed to provide no protection and contents are exposed.
Number of WPs Hit by Intrusion	[12]No calculation. Assumed 2 WPs hit adjacent to intrusion. Total WPs hit range from 0 to 170.	[13]Analysis performed. 3 packages hit on either side of dike intrusion and 1 at the dike intersection point (7 total).
Number of WPs Hit by Eruption Conduit	[14]Range 0 to 22.	[15]Range 3 to 58. Median 10.
Analysis of Eruptive Plume/Sample Size and Time	[16]17 ASHPLUME runs. All at late times.	100 plus ASHPLUME runs. Every time step.
Wind Direction	[16]Wind direction variable.	[17]Increased wind direction sampling. Direction variable or fixed at south.

Sources: [1]DOE 1998b, Vol. 2, Section 5, p. 8-15; [2]CRWMS M&O 1999a; [3]DOE 1998a, Vol. 3, pp. 2-13 to 2-15; CRWMS M&O 1998b, p. 10-38; [4]CRWMS M&O 1998b, pp. 10-22, 10-31; [5]CRWMS M&O 2000a, Section 6.3; [6]CRWMS M&O 1998b, p. 10-32; [7]CRWMS M&O 2000l, Section 6.1; [8]CRWMS M&O 1998b, p. 10-23; [9] CRWMS M&O 2000b, Section 6; [10]CRWMS M&O 1998b, pp.10-27 to 10-32; [11]CRWMS M&O 2000l, Section 6.2; [12]CRWMS M&O 1998b, pp. 4-86, 10-45 to 10-46; [13]CRWMS M&O 2000e, Section 6; [14]CRWMS M&O 1998b, p. 10-22; [15]CRWMS M&O 2000k, Tables II-6, II-13; [16]CRWMS M&O 1998b, p. 10-41; [17]CRWMS M&O 2000l, Section 6.1.2; [18]CRWMS M&O 2000k, Figure I-8

NOTE: The EDA II Design case is used as the example for the TSPA-SR.

Both TSPA-VA and TSPA-SR used the hazard results from the PVHA. As discussed in Section 3.1.1.1 of this Disruptive Events PMR, for TSPA-SR the PVHA hazard results were updated to be appropriate for EDA II, Design B (CRWMS M&O 1999a).

The results of volcanism analysis are more sensitive to some parameters than others, and the TSPA-SR analyses resulted in changes in parameter values to which the TSPA is sensitive. Waste and ash particle sizes and wind direction and speed are important to dose results, as is the number of WPs hit during an event. Analyses supporting development of several of these parameters were improved through the disruptive events calculation *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k) and an analysis of waste particle size performed within the AMR *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2000o). A portion of the waste particle size analysis is provided as Attachment A to this PMR.

For TSPA-VA, the peak waste concentration calculated from direct release (TSPA-SR volcanic eruption) was approximately 4.914×10^{-11} g/cm^2 and occurred with a due south wind direction and 23 WPs available to be entrained in the eruption (CRWMS M&O 1998b, p. 10-41). (Note: Table 10-10 of the TSPA-VA Technical Basis Document [CRWMS M&O 1998b] gives the range of number of packages hit by circular conduits [0-22] as stated in the Disruptive Events PMR, Table 3-9, and page 10-41 of the Technical Basis Document contains the statement about peak concentration of waste occurring in an eruption that entrains 23 packages.) Analyses for TSPA-SR will be reported in the TSPA-SR documentation.

For TSPA-VA, the peak waste concentration calculated from direct release (TSPA-SR volcanic eruption) was approximately 4.914×10^{-11} g/cm^2 and occurred with a due south wind direction and 23 WPs available to be entrained in the eruption (CRWMS M&O 1998b, p. 10-41). [Note: Table 10-10 of the TSPA-VA Technical Basis Document (CRWMS M&O 1998b) gives the range of number of packages hit by circular conduits (0-22) as stated in the Disruptive Events PMR, Table 3-9, and page 10-41 of the Technical Basis Document contains the statement about peak concentration of waste occurring in an eruption that entrains 23 packages.] Analyses for TSPA-SR were not complete at the time of closure of this Disruptive Events PMR.

3.1.6 Volcanism FEPs in the AMR Features, Events, and Processes: Disruptive Events

In Section 2.1.4 of this Disruptive Events PMR, the approach to FEPs analysis was discussed, and in that section it was noted that the primary purpose of the disruptive events FEPs AMR was to identify and document the analysis, screening decision, and TSPA disposition (or screening argument) for the 21 primary FEPs that were recognized as disruptive events FEPs. Disruptive events FEPs represent natural systems processes that have the potential to significantly affect repository performance events. The FEPs are related to geologic processes such as structural deformation, seismicity, and igneous activity. The eight disruptive events FEPs related to volcanism are listed in Table 3-10.

Table 3-10. FEPs Related to Volcanic Activity

YMP FEP Database Number	FEP Name
1.2.04.01.00	Igneous activity
1.2.04.02.00	Igneous activity causes changes to rock properties
1.2.04.03.00	Igneous intrusion into repository
1.2.04.04.00	Magma interacts with waste
1.2.04.05.00	Magmatic transport of waste
1.2.04.06.00	Basaltic cinder cone erupts through the repository
1.2.04.07.00	Ashfall
1.2.10.02.00	Hydrologic response to igneous activity

Source: CRWMS M&O 2000h

As shown in Table 2-2 (Section 2.1.4.3), three of the FEPs are "Excluded from the TSPA-SR" based on low consequence to dose arguments. FEP 1.2.04.02.00 "Igneous activity causes changes to rock properties" was excluded based primarily on the minimal areas of disturbance as noted at natural-analogue sites. These studies indicated that the host rock was affected only 5 to 10 meters away from the dike and that there was no evidence suggesting large mass transfer by hydrothermal means or extensive alteration or brecciation zones (Valentine et al. 1998, Chapter 5). FEP 1.2.10.02.00 "Hydrologic response to igneous activity" was excluded based on the findings of Valentine et al. (1998, Chapter 5) and the observation that the orientation of the dikes is likely to be parallel to existing maximum principal SZ transmissivity, consistent with the existing fault and fracture orientation (Ferrill et al. 1999, p. 1). The orientation of dikes, therefore, is unlikely to affect the groundwater flow regime. The aspect of FEP 1.2.04.05.00 "Magmatic transport of waste" was excluded for magmatic flow on the surface, because the largest area of extrusive events was no larger than one km from the eruptive center (CRWMS M&O 2000b, Section 6.2, Table 2) compared to the distance of 20 km from the repository to the critical group. The aspect of waste entrainment and transport in volcanic ash (which might be considered a subset of FEP 1.2.04.05.00) is covered in FEP 1.2.04.07.00, "Ashfall," which is "Include" for the TSPA.

The FEP 1.2.04.01.00 "Igneous Activity" is broad by definition. Direct effects such as intrusion and eruptive events are "Included in the TSPA-SR" as described for the more specific FEPs. Indirect effects, such as changes in topography, sealing of faults, and changes in groundwater temperature, are "Excluded from the TSPA-SR" because of the minimal scale of effects noted in analogue studies as described in the AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a, Section 6.2, Table 2) and in Valentine et al. (1998, Chapter 5).

The remaining volcanic disruptive events FEPs are "Included in the TSPA-SR," and the method of inclusion is summarized in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h), and how they are included is described within the disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l).

3.1.7 Comparison of ASHPLUME Model Results to Representative Tephra Fall Deposits

To provide additional confidence in the appropriateness of the ASHPLUME code for modeling volcanic eruptions a calculation was performed (CRWMS M&O 2000ac) that compared the ASHPLUME prediction of ash (tephra) deposits with an actual eruptive event at the Cerro Negro volcano in 1995 (Hill et al. 1998). The calculation activity also compared results for Version 1.4LV of ASHPLUME used for TSPA-SR with Version 2.0 that may be used in future calculations; however, that activity is not important to disruptive events analysis at this time. The portion of the conclusions in the calculation that is related to Version 2.0 was considered TBV at the time of finalizing this PMR because that version of the code had not completed qualification activities. The calculation only examined ash thickness outputs (it should be noted that the calculation did not include any estimates in regards to spent fuel). The calculation comparison to the Cerro Negro eruption used data for ash thickness measured downwind from a 1995 eruption (Hill et al. 1998).

At distances greater than 10 km from the volcano, ASHPLUME results for ash thickness compared favorably with the data from the 1995 eruption. At distances less than 10 km from the volcano, ASHPLUME results produced a greater ash thickness than that observed in the 1995 eruption. Results for distances of greater than 10 km are applicable to the critical group, located 20 km from the potential repository, and show the best agreement.

This calculation provided a check on the appropriateness of ASHPLUME for use in modeling ashfall for an eruption of the type that may occur at the potential repository site. The disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) provided the primary basis for recommending ASHPLUME as an appropriate code and recommended that ASHPLUME be used in the TSPA-SR. Though the calculation did not provide input to another activity within the group and was not part of the disruptive events group of analyses/calculations, its topic is discussed in this PMR because it is most directly related to volcanism.

3.2 SUMMARY OF DISRUPTIVE EVENTS AMRs SUPPORTING ANALYSIS OF SEISMICITY AND STRUCTURAL DEFORMATION

Section 2.2.3 contains an overview of how the disruptive events analyses for the effects of seismicity and structural deformation for TSPA-SR fit together. These analyses examine the effects of ground motion and fault displacement based on hazard curves developed by the PSHA (Wong and Stepp 1998). Figure 2-17 (Section 2.2) shows the relationship of the disruptive events seismicity and structural deformation AMRs to each other. Sections 3.2.1 through 3.2.4 provide summaries of the individual AMRs supporting the ground motion and fault displacement analyses for TSPA-SR. The way in which the AMRs support addressing NRC IRSR KTIs is discussed in Chapter 4 of this report and will not be contained in the AMR summaries.

3.2.1 Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada

The purpose of the AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c) was to summarize the PSHA (Wong and Stepp 1998) to support preparation of this Disruptive Events PMR. A summary of the PSHA taken from the AMR is provided in Section 2.1.3 of this PMR and is not repeated in the AMR summary section of this PMR. The PSHA was the result of the expert elicitation that forms the basis for seismic probability analyses for TSPA-SR for the potential repository at Yucca Mountain. The seismic framework AMR provides a summary level discussion of the process followed for the expert elicitation, the seismotectonic framework for the Yucca Mountain region as evaluated in the PSHA, and the results of the PSHA. The purpose of the AMR included summarizing how tectonic processes and models for the Yucca Mountain site were considered and evaluated in the PSHA. This information shows that no single model was selected for YMP use, however uncertainty in understanding of the tectonic framework for the site was quantitatively assessed as part of the hazard analysis.

Table 3-11 summarizes key points of the AMR. The discussion below will describe how hazard curves from the PSHA are used by the Project and summarize the conclusions of the AMR.

3.2.1.1 Use of Seismic and Fault Displacement Hazards by the YMP

Seismic hazards potentially affecting the Yucca Mountain site consist of vibratory ground motion and fault displacement. The TSPA-SR analysis used both the probability of their occurrence and their effects (consequences) on engineered and natural systems. The seismic framework AMR summarized the probability information. Consequence analyses were performed by the engineered barriers, WP, and waste form groups in analyses summarized in three PMRs (CRWMS M&O 2000t, 2000u, 2000v). Two AMRs supporting this Disruptive Events PMR examined fault displacement consequences: *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i) and *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g). Those AMRs will be discussed in Sections 3.2.2

and 3.2.3, respectively, of this Disruptive Events PMR. These AMRs and other activities for SR and LA require ground motion and fault displacement data from the PSHA study.

Table 3-11. Summary of Key Points for Disruptive Events AMR Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada

Assumptions
No assumptions. This AMR summarizes the results of the PSHA expert elicitation project and describes key assumptions for that project.
Inputs
PSHA expert interpretations of: a) Seismic source characterization and ground motion attenuation characterization. b) Fault displacement potential.
Outputs
Summary of process and results of PSHA project.
Overview of Analysis Method
Summarize process and results of PSHA project.
AMRs or Other Analyses Receiving Outputs
Summary of PSHA process and results will have general use by reports needing a summary of the PSHA.
Concepts Developed or Processes Constrained
No development of concepts. Summarized PSHA results as follows: a) Ground motion hazard calculated for Point A (ground surface at elevation of repository) is comparable to moderate tectonically and seismically active sites elsewhere in the Basin and Range Province. b) Approaches to fault displacement hazard were developed for Yucca Mountain and hazard results indicate that fault displacement is not a seismic design issue for the repository, although block-bounding faults should be avoided in the layout of underground facilities.

Source: CRWMS M&O 2000c

Seismic hazard results from the PSHA are used in several areas of analysis for the potential repository. The results are being used for postclosure analysis to evaluate whether future ground motions or fault displacements with a probability of occurrence greater than 1 in 10,000 in 10,000 years could have significant effects on overall performance. An event for this purpose, is the failure of an SSC to perform its functional goal under ground shaking or fault displacement loading.

Ground motion hazard results are also being used to develop preclosure seismic design inputs for the potential repository. PSHA ground motion hazard results form the basis for identifying the controlling design earthquakes and controlling ground motion spectra appropriate for the proposed Geologic Repository Operations Area. The inputs will be used to design SSCs that accommodate the ground motion to preserve safety and waste isolation functions. Although supported by the disruptive events analyst group, preclosure seismic issues are not part of the scope of this Disruptive Events PMR. Preclosure design issues are addressed in a series of three topical reports, two of which are completed and one of which will be completed after TSPA-SR. These topical reports are discussed in Section 2.1.3.1 of this Disruptive Events PMR.

3.2.1.2 Summary of the PSHA

The disruptive events AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c) contains a detailed summary of the PSHA.

A summary of the PSHA for the Disruptive Events PMR is provided in Section 2.1.3 of this Disruptive Events PMR.

3.2.1.3 Conclusions of AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*

The conclusions for this AMR (CRWMS M&O 2000c, Section 7) are the same as those for the PSHA report (Wong and Stepp 1998). The earthquake hazards from ground shaking and fault displacement have been evaluated for the potential geologic repository at Yucca Mountain using multiple expert interpretations to capture uncertainty in the data and earthquake processes. The resulting level of ground motion hazard, calculated for a defined rock condition (Point A on Figure 2-11), is comparable to moderately tectonically and seismically active sites elsewhere in the Basin and Range province (Wong and Olig 1998). Horizontal peak ground accelerations at Yucca Mountain with annual exceedance frequencies of 10^{-3} and 10^{-4} are 0.169 and 0.534 g, respectively. Hazard values at Yucca Mountain are lower than elsewhere in the Basin and Range tectonic province, such as locations along the Wasatch fault in central Utah.

The approach used in the PSHA to evaluate fault displacement hazard was developed specifically for the Yucca Mountain site and still represents the state of the art for this type of hazard evaluation. The results of the PSHA indicate that fault displacement hazard is not a preclosure seismic design issue for the potential repository, although block-bounding faults should be avoided in the layout of the underground facilities in accordance with Seismic Topical Report 2 (YMP 1997b). The AMR discusses this in further detail in Section 6.6.3 (CRWMS M&O 2000c).

3.2.2 Fault Displacement Effects on Transport in the Unsaturated Zone

The analyses performed for the AMR *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i) were conducted to evaluate the potential for fault displacement to change the hydrogeologic system in a way that would subsequently affect radionuclide transport in the UZ at Yucca Mountain. This analysis was initiated to support screening arguments for several FEPs that involve geologic concepts in faulting, seismicity, and hydrology. The FEPs supported by the analysis are listed at the end of Section 2.2.3 in this Disruptive Events PMR, and screening arguments supported by this AMR are contained in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h). Table 3-12 summarizes key points of the AMR. The discussion following the table is summarized from the AMR and provides selected details supporting the table. For more detail and supporting references, see the AMR.

3.2.2.1 Summary of AMR *Fault Displacement Effects on Transport in the Unsaturated Zone*

The potential effects of fault displacement on transport in the UZ are addressed in this AMR. A sensitivity analysis that is conducted by perturbing, or altering, fracture parameters is used. Geological information for the Yucca Mountain site has been used as a basis for defining the extent of perturbations caused by fault displacements. The block in which the potential repository is located is bounded on the west by the Solitario Canyon fault and on the east by the

Bow Ridge fault (see Figure 2-1). The northern boundary of this structural block is bounded by the Drill Hole Wash fault. In addition, there are intrablock faults consisting of the Ghost Dance, Sundance, and Dune Wash faults.

Table 3-12. Summary of Key Points for Disruptive Events AMR *Fault Displacement Effects on Transport in the Unsaturated Zone*

Assumptions	
1	The TSPA-SR UZ flow model and its active fracture parameters are judged to be adequate to represent UZ flow and transport processes, even when the fracture parameters are perturbed to reflect potential fault displacement effects.
2	Effects of fault displacement on radionuclide transport in UZ are entirely the result of changes to fracture properties in the fault zone and/or the surrounding rock. Effects on matrix properties negligible.
3	Changes in fracture properties come from dilation or compression of existing fractures rather than from generation of new fractures.
4	Effects of fault displacement on mountain-scale UZ transport can be evaluated from response of a simulated non-diffusing, non-sorbing tracer.
5	Fracture property changes are uniform over the area analyzed.
6	Transient effects of changes in fracture properties can be neglected (i.e., transport for steady flow equilibrated to changed conditions bound effects of the change).
7	Water table elevation is unchanged by fault displacement.
8	The TSPA-SR UZ flow model based on a dual-permeability, active fracture conceptualization is judged adequate to represent UZ flow in this sensitivity study.
9	Fault displacements may change perched water, but effects of perched water zones on radionuclide transport are negligible.
10	Thermal-hydrologic processes from waste heat will affect UZ flow and transport, but effects are negligible for purposes of this study.
Inputs	
1	Data and parameter inputs from TSPA-SR 3-D UZ flow and transport model.
2	Dispersivity value of 25 m.
Outputs	
1	Fracture aperture changes confined to fault zones have virtually no effect on transport.
2	Breakthrough of radionuclides is found to occur for an extremely conservative ten-fold increase in fracture aperture applied over the entire UZ domain.
Overview of Analysis Method	
1	Evaluation of two end-member cases: a) Change in fracture properties throughout UZ model domain with strain uniformly distributed throughout strata bounded by faults with change in fracture aperture throughout. b) Change in fracture properties in fault zones only, with strain localized to the fault zone, with change in fracture aperture in fault zone.
2	Evaluation performed using UZ 3-D Flow Model simulations.
3	Present-day climate and wetter longer-term climate used for infiltration input.
4	Tracer breakthrough curves computed at water table used to examine potential impact on UZ transport.
AMRs or Other Analyses Receiving Outputs	
	Features, Events, and Processes: Disruptive Events (CRWMS M&O 2000h) to support a screening decision for FEPs 1.2.01.01.00, 1.2.02.01.00, 1.2.02.02.00, 1.2.03.01.00, 1.2.10.01.00, 2.2.06.01.00, and 2.2.06.02.00.
Concepts Developed or Processes Constrained	
1	Transport between potential repository and water table is only weakly coupled to changes in fracture aperture. Large changes in fracture aperture correlate to small changes in transport behavior.
2	Ten-fold increase in fracture aperture is an extremely conservative scenario, therefore though some early breakthrough resulted from calculation of that effect, it is negligible to TSPA results.
3	Models for TSPA-SR may exclude the effects of fault displacement on UZ transport.

Source: CRWMS M&O 2000i

A bounding approach is used to assess the potential effects of fault displacement on the performance of the potential repository. The spatial distribution of changes to fracture aperture within the modeling domain is treated using two end-member scenarios: (1) all fracture apertures are altered uniformly throughout the UZ model domain (both fault zones and fractured rock) and (2) only fracture apertures in the fault zones are altered. These two end-member scenarios relate to the mechanical strain either being distributed throughout the strata bounded by the faults or being localized to the individual fault zones. The first scenario bounds the most widespread disturbance possible. The second scenario addresses the possibility that the effects of fault displacement remain local to the fault zones. The second scenario is also used to investigate the potential sensitivity associated with an enhanced contrast in properties between the fault zones and the fractured rock. The two scenarios were evaluated by simulating the flow and transport in the UZ for a pulse input tracer at the potential repository location.

In the previous revision of this AMR simulations were performed for the present-day climate and a wetter longer-term average climate case. Tracer breakthrough curves computed at the water table were used to examine the potential impact induced on UZ transport. The model used was the unqualified UZ flow model used in TSPA-VA. The data generated by the previous revision of the AMR has been superceded by data generated in the subsequent revision and the previous revision is mentioned to provide traceability for the historical progress of this analysis.

The flow and radionuclide transport calculations in the current revision of the AMR (CRWMS M&O 2000i) are conducted by using the TSPA-SR UZ model, which has been modified to include concepts such as the active fracture concept. This model is a 3-D dual-permeability model constructed with the active fracture concept, in which only a portion of the fracture network is hydraulically active and only this active portion is in hydraulic contact with the rock matrix. Fracture aperture and related parameters are perturbed according to theoretical relationships, and then flow and transport calculations are conducted and compared with the nominal base cases, for both the present-day (dry) climate and the long-term, glacial-transition (wetter) climate.

A number of primary controls on fracture characteristics within the rocks composing Yucca Mountain are related to stratigraphy, upon which any later tectonic signature (such as fault displacement) is superimposed. Fracture characteristics in the pyroclastic flows at Yucca Mountain are primarily controlled by variations in the degree of welding. The intensity of fracturing increases with degree of welding within the welded pyroclastic flows because of the presence of cooling joints, and because increasing brittleness of the rock favors an increase in the number of tectonic joints. Lithophysal development, alteration, and pumice content are secondary controls important in specific stratigraphic intervals. These lithostratigraphic controls affect fracture spacing, type, number of sets, and continuity of individual fractures within each lithostratigraphic zone; they also affect the fracture connectivity of the network as a whole.

Each lithostratigraphic zone at Yucca Mountain has characteristic fracture attributes, including orientation, spacing, trace length and joint type, so each is unique in its ability to deform by distributed slip. The result is stratigraphic control of structural geometry: what may be a discrete break in one lithostratigraphic unit may be a broad zone of distributed deformation in another.

The fracture network acts as a significant pre-existing weakness in the rock mass that can accommodate extensional strain through distributed slip along many fractures. The existence of distributed slip suggests that changes in strain (such as would be associated with a significant fault displacement) are likely to be propagated throughout the repository area. Also, some faults (such as the Ghost Dance and Solitario Canyon) may consist of fault zones on the order of 100 to 400 m wide at the surface. These observations suggest that the effect of strain distributed in the fractures throughout the repository should be considered.

Fault displacements are expected to occur along existing faults in the vicinity of Yucca Mountain. The movement on a fault will result in changes in the rock stress in the vicinity of the fault, which will decrease with distance away from the fault. However, the magnitude of the changes in rock stress as a function of distance from the fault depends on the specific details of the fault displacement (magnitude of fault motion, direction of fault movement, extent of the fault that participates in the movement, etc.) and the mechanical properties of the surrounding rock (fracture spacing, fracture stiffness, geomechanical properties of the rock matrix, etc.). Given some change in rock stress, the fractured rock mass will respond to the change in stress through deformation, or strain, in the rock. Of particular importance is the fact that this induced strain can affect the geometry of fractures in the rock.

3.2.2.2 Conclusions of AMR *Fault Displacement Effects on Transport in the Unsaturated Zone*

Sensitivity studies for UZ flow and transport presented in the AMR suggest that transport between the potential repository and the water table is only weakly coupled to changes in fracture aperture (CRWMS M&O 2000i). Overall, for the TSPA-SR 3-D UZ Flow Model, small changes in transport behavior are found for large changes in fracture aperture. Changes in fracture aperture confined to the fault zones show virtually no effect on transport behavior. Changes in fracture aperture, up to a five-fold increase over the entire UZ domain, show virtually no effect on transport behavior. Some breakthrough is found to be, at most, earlier by about one order of magnitude than for the base case (under the present-day or the glacial-transition climate). An extremely conservative ten-fold increase in fracture aperture applied over the entire UZ domain was an assumption used in this analysis. Effects on travel time of this magnitude are no more significant than those caused by the uncertainties in other parameters, such as infiltration. Therefore, models for TSPA-SR may exclude the effects of fault displacement on UZ transport.

Although faults and fractures are known to be important conduits for flow and transport in the UZ, the flow rates moving through the faults and fractures are very small in comparison with their capacity under a unit (gravitational) hydraulic gradient. For present or future climates, the average percolation flux through the UZ is on the order of 1 to 100 of mm/yr. The flow capacity of the fracture system is on the order of 10,000 to 1,000,000 mm/yr. Therefore, we would expect the flow to be insensitive to the value of the fracture permeability, unless the permeability was decreased to a level approaching 100 mm/yr. This expectation was borne out by the sensitivity study, with the caveat that some effects on the flow and transport were found when fracture permeabilities were increased by a factor of 1,000 or more throughout the UZ flow domain. The reason for this sensitivity is discussed in the AMR. Transport is also expected to be insensitive because changes in fracture porosity with aperture are roughly offset by change in water saturation. For example, with an increase in aperture (and hence fracture porosity), water saturation will decrease to maintain the same water flux. Therefore, the product of water saturation and porosity, which is an important factor for transport velocities, is also insensitive to aperture change.

3.2.3 Effects of Fault Displacement on Emplacement Drifts

The analyses for the AMR *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g) were conducted to evaluate potential effects of fault displacement on emplacement drifts, including drip shields and WPs in the drifts. The primary scope of the analysis includes: (1) examining fault displacement effects in terms of induced stresses and displacements in the rock mass surrounding an emplacement drift, and (2) predicting fault displacement effects on the drip shield and WP.

Table 3-13 summarizes key points of the AMR. The discussion following the table provides selected details supporting the table and is summarized from the AMR. For more detail and supporting references see the AMR.

Table 3-13. Summary of Key Points for Disruptive Events AMR *Effects of Fault Displacement on Emplacement Drifts*

Assumptions	
1	Displacement along fault assumed to be constant.
2	Two orientations of normal fault plane evaluated. a) Parallel to drift axis. b) Perpendicular to drift axis.
3	One orientation of strike slip fault plane evaluated is the parallel to drift axis with drifts directly under fault.
4	Planar fault plane assumed for all faults.
5	Width of fault zone virtually zero.
6	Fault length assumed to be infinite with length in area of displacement either 100, 200, 300 or 400 m.
7	Vertical in situ stress is gravitational; Horizontal in situ stress is 0.3 to 1.0 times the vertical stress.
8	Distance from emplacement drift to fault ranges from 0 to 100 m.
9	Depth of faulting assumed to be greater than length of fault where displacement occurs.
10	For normal or reverse fault, angle of dip is not considered in computing stresses or displacements.
11	Fault displacement ranges from 0.1 to 100 cm bounds mean values.
12	Largest mean preclosure displacement from PSHA is 32 cm (Solitario Canyon); therefore 100 cm displacement extends into postclosure range.
13	Rock mass quality categories for the TSw2 thermal/mechanical unit.
14	Rock mass property values. a) Modulus of elasticity. b) Poisson's ratio. c) Shear modulus.
15	PSHA fault displacement values with mean of <0.1 to 32 cm corresponding to annual frequency of exceedance of 10^{-5}.
16	For annual exceedance probabilities below 10^{-5} mean is from PSHA results.
Inputs	
Not applicable.	

Table 3-13. Summary of Key Points for Disruptive Events AMR *Effects of Fault Displacement on Emplacement Drifts* (Continued)

Outputs	
	Depending on the location of a fault relative to the emplacement drift location, fault displacement could induce detectable stresses and rock movement at the emplacement drift vicinity. These induced stress levels are not considered to be detrimental to drift stability.
Overview of Analysis Method	
	Closed-form solutions of simplified diagrams of normal and strike-slip faults to assess effects of fault displacement on drift, drip shield, and WP.
AMRs or Other Analyses Receiving Outputs	
1	Results support preclosure design analyses for EBS group.
2	AMR *Features, Events, and Process: Disruptive Events* (CRWMS M&O 2000h) to support a screening decision for FEPs 1.2.02.02.00 and 1.2.02.03.00.
Concepts Developed or Processes Constrained	
1	Conclusion that stress levels calculated are not considered to be detrimental to drift stability.
2	Conclusion that backfill acts as a soft inclusion in a solid and will draw less stress than surrounding rock; therefore stresses induced in backfill would be negligibly small unless fault displacement was >1 m.
3	Conclusion that a negligible induced load in backfill renders any induced load in a drip shield negligible; therefore effects of fault displacement on drip shields is no concern as long as drifts are not directly intersected by a fault.
4	Drip shield and WP stress analysis is similar, so WPs are unlikely to be subject to loading effects induced by fault displacement whether backfill is present or not.
5	The effects of loads other than normal or shear (such as bending or twisting) could be induced, subjecting drip shield and WP to rotation, distortion, or twisting. Though not investigated by this analysis, they can be eliminated from concern because of the low probability of a new fault intersecting a drift.
6	It is uncertain whether results calculated at a 100 cm fault displacement value are adequate to cover annual exceedance probabilities lower than 10^{-5}.

Source: CRWMS M&O 2000g

3.2.3.1 Summary of AMR *Effects of Fault Displacement on Emplacement Drifts*

The output of the AMR analysis provides data for the evaluation of long-term drift stability and supports both postclosure PA FEPs screening for the disruptive events analysis and preclosure design analysis for the EBS group. The analysis included a literature survey on accommodating fault displacements encountered by underground structures such as buried oil and gas pipelines, which provide analogs for potential emplacement drift responses. The AMR analysis also included calculating closed-form solutions for simplified diagrams of normal and strike-slip faults to assess the effects of fault displacement on a drift, drip shield, or WP. The approach followed, maximized the effects of fault offset by using the least favorable scenario for spatial relationships of faults to drifts. The fault displacement range from 0.1 to 100 cm was assumed in the analysis. This assumption bounds the mean values developed for the PSHA for the preclosure period (Wong and Stepp 1998). Potential consequences of fault displacement on emplacement drifts were analyzed by calculating loads (stresses) that might be induced on the drift, drip shield, and/or WPs. The analysis indicated that reverse faults would have effects similar to those of normal faults, therefore, only normal and strike-slip fault scenarios were analyzed.

At the time of the analysis there were no engineering fault displacement acceptance criteria against which to compare results. Such criteria would represent tolerances for loads and induced damage on EBS components in response to fault displacement when fault avoidance could not be achieved in the drift design process. In the analysis it was assumed that, if a fault intersected a circular repository emplacement drift, the shape of the drift could be changed due to a fault movement (i.e., fault displacement). This could possibly impede the operational envelope requirement and transfer some loads to structures such as drip shields or WPs when backfill is present. If the drift wall was sheared and offset by a fault, the ground support system could be loaded and could deform, resulting in rockfalls. This series of hypothetical occurrences indicates that engineering acceptance criteria would be required for emplacement drift clearance, ground support systems, and WPs/drip shields.

When design fault displacements are determined, calculations to assess performance include determination of the resulting loads (stresses) and deformations (strains) in the systems of importance. Drift lining and rock mass stiffness, and drift lining configuration, are incorporated in these calculations. Fault displacement loads are generally localized and often cause inelastic response (depending on the flexibility of the structures being loaded), so strain-based acceptance criteria are preferable to stress-based ones in establishing design adequacy (YMP 1997b). For WPs and drip shields strain-based acceptance criteria could be established that provide the maximum level of tolerance of fault displacement-induced strain if they were to be affected by a fault that was not detected during setbacks. The calculations produced by the AMR could aid in assessing adequacy of performance if such a fault displacement event occurred.

For the analysis, the assumptions are listed in Table 3-13. Hypothetical fault orientations with respect to an emplacement drift were used to aid in evaluating fault displacement effects on emplacement drifts.

3.2.3.2 Conclusions of AMR *Effects of Fault Displacement on Emplacement Drifts*

The effects of fault displacement on emplacement drifts, drip shields, and WPs were assessed, based on simplified models of normal and strike-slip faults. These effects were described in terms of displacement and stress induced by fault displacement. The following conclusions were drawn:

- Effects of fault displacement on drip shields were evaluated by treating fault displacement effects on an unexcavated emplacement drift location as a bounding scenario. Backfill present in an emplacement drift acts as soft inclusion in a solid and will draw less stress than the surrounding stiff medium. Partly because of backfill's high compressibility due to its voids, and partly because of the presence of gaps between backfill and drift wall, particularly above the spring line, it was estimated that stresses induced by fault displacement in backfill, if any, would be negligibly small unless a fault displacement over a meter in magnitude occurs. A negligible induced load in backfill renders any induced load in a drip shield negligible. Consequently, the effects of fault displacement on drip shield are of no concern when emplacement drifts are not directly intersected by faults.

- Depending on the location of a fault relative to the emplacement drift location, fault displacement could induce detectable stresses and rock movement at the emplacement drift vicinity. These induced stress levels are not considered to be detrimental to drift stability.

- Similar to drip shields, WPs are unlikely to be subject to loading effects induced by fault displacement regardless of the presence or absence of backfill.

- Evaluation results presented in this analysis support the fault avoidance design criterion. The Bow Ridge and Solitario Canyon faults may induce considerable stress and rock movement when they are close to emplacement drifts, thus fault avoidance is especially prudent for any faults with comparable displacements.

3.2.4 Seismicity and Structural Deformation FEPs in the AMR Features, Events, and Processes: Disruptive Events

In Section 2.1.4 the approach to FEPs analysis was discussed, and it was noted that the primary purpose of the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) was to identify and document the analysis, screening decision, and TSPA disposition (or screening argument) for the 21 primary FEPs that were recognized as disruptive events FEPs. These FEPs represent natural systems events and processes that have the potential to be, or cause, disruptive events. The FEPs are related to geologic processes such as structural deformation, seismicity, and igneous processes. In this section of the Disruptive Events PMR, FEPs related to seismicity and structural deformation will be discussed together. The two processes are linked through the tectonic framework of the Southern Basin and Range tectonic province. These FEPs are listed in Table 3-14.

The consideration and evaluation of seismic effects is based on the results of the *Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada* (Wong and Stepp 1998). The magnitude and characteristics of the ground motion events are quantified in that document, and the application to the TSPA is described in *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c).

In the case of FEP 1.2.03.02.00 "Seismic vibration causes container failure," seismic damage to the fuel-rod cladding is "Included in the TSPA-SR." Damage to the exterior WP and drip shield are listed as "Excluded from the TSPA-SR (Preliminary)." At the time of finalizing the PMR, analyses to resolve TBV data in the originating AMRs cited to support this screening decision were ongoing. The current arguments are qualitative in nature and support an "Excluded from the TSPA-SR (Preliminary)" decision which is appropriate at the current level of conceptual design.

FEP 1.2.03.03.00 "Seismic activity associated with igneous activity" was evaluated within the PSHA calculations and is not considered separately. Since the PSHA includes seismic hazard calculations (i.e., since all types of seismic activity were integrated within the PSHA calculations), this FEP is treated in TSPA-SR in a manner that is the same as that for seismic activity not associated with igneous activity.

Table 3-14. FEPs Related to Seismicity and Structural Deformation

YMP FEP Database Number	FEP Name
1.2.03.01.00	Seismic activity
1.2.03.02.00	Seismic vibration causes container failure
1.2.03.03.00	Seismicity associated with igneous activity
1.2.01.01.00	Tectonic activity–large scale
1.2.02.01.00	Fractures
1.2.02.02.00	Faulting
1.2.02.03.00	Fault movement shears waste container
1.2.10.01.00	Hydrologic response to seismic activity
2.1.07.01.00	Rockfall (large block)
2.1.07.02.00	Mechanical degradation or collapse of drift
2.2.06.01.00	Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock
2.2.06.02.00	Changes in stress (due to thermal seismic, or tectonic effects) produce change in permeability of faults
2.2.06.03.00	Changes in stress (due to seismic or tectonic effects) alter perched water zones

Source: CRWMS M&O 2000h

FEP 1.2.10.01.00 "Hydrologic response to seismic activity" is also "Excluded from the TSPA-SR (Preliminary)" based on low consequence to dose. An analysis provided in the AMR *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i) indicates, as a conclusion (Preliminary), that changes in the stress state that could affect fracture aperture, have a minimal effect on flow in the UZ. The preliminary nature of the conclusion is due to the use of TBV data (designated as such in a source document) in the analysis and the need to verify that the models used have been validated. This FEP also has been excluded, because past studies have shown the seismic effects on hydrologic conditions are transient (on the order of months or years) in nature, and that the projected water level rise (a maximum rise of 50 m) is of low consequence to the potential repository performance (Gauthier et al. 1996, pp. 163 to 164; Muir-Wood and King 1993).

FEP 1.2.03.01.00 "Seismic activity" is a broadly defined FEP. In summary, indirect effects of seismic activity, for instance fault and fracture displacement as opposed to ground motion effects, have been classified as "Excluded from the TSPA-SR (Preliminary)" on the basis of low consequence to dose. The effects of seismic activity are dealt with by more specific FEPs, some of which depend on data and conclusions that are classified as Preliminary.

The remaining FEPs are related to structural deformation issues. FEP 1.2.01.01.00 "Tectonic activity–large scale" is classified as "Excluded from the TSPA-SR" due to low consequence to dose. The low consequence conclusion stems from knowing that the process will occur, but that the rate of the process is very slow and unlikely to have significant effects during the regulatory period.

Parts of FEPs 1.2.02.02.00 "Faulting" and 1.2.02.01.00 "Fractures" are included and parts are excluded. Existing features are classified as "Included in the TSPA-SR" in the framework for geosphere modeling; changes in the existing characteristics are classified as "Excluded from the TSPA-SR (Preliminary)." The exclusions are based, in part, on the low probability of formation of new faults as concluded by PSHA expert evaluations. Creation of new features of significance are classified as "Excluded from the TSPA-SR" based on the low probability of these events occurring as presented in the PSHA (Wong and Stepp 1998). Additionally, the exclusion for significant effects occurring due to changes in fault and fracture characteristics are based, in part, on the analyses provided in the AMR *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i). This analysis indicates, as a conclusion (Preliminary), that changes in fracture aperture confined to the fault zones show virtually no effect on transport behavior, and that increased fracture aperture applied over the entire UZ domain results in effects that are no more significant than those caused by uncertainties in other parameters (CRWMS M&O 2000i, Section 7). The preliminary nature of the conclusion is due to the TBV data used for the analysis and the need to verify that the models used have been fully qualified. Consequently, changes in faults and fractures with regard to extension or reactivation of existing systems is classified as "Excluded from the TSPA-SR (Preliminary)" based on results of sensitivity studies for changes in fault and fracture characteristics.

In some instances, such as FEP 1.2.02.03.00 "Fault movement shears waste container," design features (such as set backs from faults) will be used to mitigate the hazard and are the basis for the "Excluded from the TSPA-SR" decision. Section 3.2.3 summarizes the disruptive events AMR *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g), in which this subject is discussed further.

The NRC IRSR for structural deformation and seismicity, in citing results of some of their sensitivity analyses, discusses a FEP that was analyzed by both the NRC and DOE and was determined to be excluded (NRC 1999a, p. 11). The FEP can be summarized as "faulting exhuming waste packages." Screening arguments within the Primary FEP "Faulting" are sufficiently broad to cover exclusion of this process. As the NRC IRSR notes (NRC 1999a, p. 11), even if a new block-bounding fault were to form within the repository, slip rates are sufficiently slow that "10^6-10^7 yr. would be required to exhume the WP [waste package]."

FEPs 2.1.07.01.00 "Rockfall (large block)" and 2.1.07.02.00 "Mechanical degradation or collapse of drifts" are classified as "Excluded from the TSPA-SR (Preliminary)." The consequences to dose from the effects of these processes will not significantly affect repository performance during the regulatory period. The decision is listed as Preliminary because the inputs, though based on qualified data, have not yet been qualified.

Results of the AMR *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i) also apply to FEPs 2.2.06.01.00 and 2.2.06.02.00 which, respectively, address the effects of changes in stress state on the porosity and permeability of rock matrix and faults. As previously stated, the analysis conclusions indicate (Preliminary) that changes in fracture aperture confined to the fault zones have virtually no effect on transport behavior in the UZ, and an increase in fracture aperture applied over the entire UZ domain results in effects that are no more significant than those caused by uncertainties in other parameters (CRWMS M&O 2000i, Section 7). The preliminary nature of the conclusion is due to the use of TBV data in the analysis and the need to verify that the models used have been fully qualified. Consequently, the two FEPs are classified as "Excluded from the TSPA-SR (Preliminary)."

FEP 2.2.06.03.00 deals with the effects of a changed stress state on the perched water zones. The argument for this FEP relies on volumetric arguments rather than on the sensitivity analyses presented in the AMR cited above (CRWMS M&O 2000i). This FEP has been classified as "Excluded from the TSPA-SR" based on low consequence to dose.

This concludes the discussion of seismic issues and the summaries of individual AMRs and the calculation that supported this Disruptive Events PMR. Section 3.3 and Chapter 4 provide discussions that address the concerns of oversight groups regarding the DOE's technical approach for analyzing issues related to the effects of volcanism and seismicity and structural deformation. Section 3.3 addresses concerns from several sources, and Chapter 4 addresses subissues and acceptance criteria from NRC IRSRs.

3.3 DISRUPTIVE EVENTS ISSUES FROM OVERSIGHT GROUPS

This Disruptive Events PMR addresses potential regulatory issues identified based on reviews of meeting summaries and correspondence from various oversight groups during the past two years.

The oversight groups are described below, and issues identified from the groups are listed in Table 3-15 along with cross references to documents that provide additional discussions. The NRC developed a series of IRSRs which, among other things, serve as vehicles to provide technical comments on the DOE's approach to characterization and analysis of the potential repository site (NRC 1998a, 1998c, 1998d, 1998e; NRC 1999a, 1999b, 1999c; NRC 2000; Reamer 1999). The IRSRs also contain detailed discussion of both NRC and DOE models and PA results, comments on favorably accepted approaches, and areas where there is disagreement regarding approach. The IRSR subissues and acceptance criteria and how they are addressed by disruptive events analyses are discussed in detail in Chapter 4 of this Disruptive Events PMR. The NRC uses other means to comment on the DOE's approach, including letters with subjects such as the NRC staff review of the TSPA-VA. Issues from the NRC staff letter commenting on the TSPA-VA are contained in Table 3-15.

The Advisory Committee on Nuclear Waste is a committee established by the NRC to provide independent reviews of, and advice on, nuclear waste facilities, applicable regulations, and legislative mandates.

The Nuclear Waste Technical Review Board is an independent body created by the Nuclear Waste Policy Amendments Act of 1987 to evaluate the technical and scientific validity of activities undertaken by the DOE. Activities over which the Nuclear Waste Technical Review Board has oversight include site characterization activities and activities relating to the packaging or transportation of HLW or spent nuclear fuel (SNF). Members of this Board are appointed by the President from a list developed by the National Academy of Sciences.

The TSPA Peer Review Panel was formed by the Civilian Radioactive Waste Management System Management and Operating Contractor at the request of DOE to provide a formal, independent evaluation and critique of the *Total System Performance Assessment* Volume 3 of *Viability Assessment of a Repository at Yucca Mountain* (DOE 1998a). Four review reports were provided by the TSPA Peer Review Panel: three interim reports (Budnitz et al. 1997a, 1997b, 1998) and a final report (Budnitz et al. 1999). The three interim reports were based on draft documents supplemented by formal and informal meetings and interactions with the TSPA-VA staff. The comments provided in the final report were based on documented work describing the completed TSPA-VA and its supporting Technical Basis Documents (CRWMS M&O 1998b) and on other documents cited in the final peer review report (Budnitz et al. 1999, p. 1).

In addition, correspondences received during the last two years from the State of Nevada, Affected Units of Government (generally Native American tribal governments, and county and local governments that could be affected by development of the repository), and private parties were reviewed. Transcripts from meetings attended by these groups and private parties were also reviewed.

Table 3-15 provides a summary description of how various issues identified by the above groups, and related to disruptive events, are addressed by information in this Disruptive Events PMR or in its supporting AMRs and calculation. Cross references are given to documents that provide additional discussions.

Table 3-15. Summary of Potential Regulatory Issues from Oversight Groups and How They Are Addressed by Disruptive Events Analyses

Issue	Description	Source	PMR Approach
1	The Advisory Committee on Nuclear Waste raised the issue of the causes of differences in probabilities obtained by different methods and the significance of those differences. A larger issue identified is the difference between treatments of probabilities for Viability Assessment (VA) and for SR.	91st Advisory Committee on Nuclear Waste Transcript (NRC 1997, p. 5)	The probabilities of volcanism used in the TSPA-VA and TSPA-SR are the same and are those developed in the PVHA. Disruptive Events AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) discusses the causes of differences in probabilities obtained by different methods and the significance of those differences. The AMR is discussed in Section 3.1.1 of this report. Treatment of volcanism for TSPA-SR is summarized in Table 3-9 of the Disruptive Events PMR and discussed in the AMR.
2	The Advisory Committee on Nuclear Waste raised the issue of how consequences of igneous activity are being investigated and the results of those investigations. An associated question concerned the appropriateness of the Suzuki model [a model for tephra dispersion].	91st Advisory Committee on Nuclear Waste Transcript (NRC 1997, p. 5)	Disruptive Events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) describes the work to investigate igneous consequences. The descriptions in the AMR include the use and appropriateness of the Suzuki model (CRWMS M&O 2000l, Section 6.1). The AMR is discussed in Section 3.1.5 of the Disruptive Events PMR.
3	The Advisory Committee on Nuclear Waste raised the question of how indirect effects of igneous activity are being studied.	91st Advisory Committee on Nuclear Waste Transcript (NRC 1997, p. 5)	Disruptive Events AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) provides analyses of some of the indirect effects of volcanism, such as alteration of the country rocks adjacent to dikes by magmatic fluids and gases. The AMR is discussed in Section 3.1.2 of the Disruptive Events PMR.

Table 3-15. Summary of Potential Regulatory Issues from Oversight Groups and How They Are Addressed by Disruptive Events Analyses (Continued)

Issue	Description	Source	PMR Approach
4	The NRC view of the issue of volcanic disruption of the WP is described. The staff concluded … "(i) these analyses are on assumptions of physical conditions that are not representative of Yucca Mountain basaltic volcanism, (ii) data are insufficient to evaluate WP and high-level radioactive waste(HLW) behavior under appropriate physical conditions, and (iii) model assumptions are incongruent with those used elsewhere in the TSPA-VA, for example, in enhanced source-term analyses."	NRC Staff Review of VA (Paperiello 1999, p. 13)	Disruptive events AMRs *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) and *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) provide detailed descriptions of the physical conditions that are representative of basaltic volcanism at Yucca Mountain. The *Waste Package Behavior in Magma* (CRWMS M&O 1999b) calculation that supports the Waste Package PMR and Disruptive Events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) describes physical conditions appropriate to the evaluation of WP and HLW behavior in the presence of basaltic igneous activity. For the issue in iii the TSPA-SR uses the same assumption regarding volcanic disruption of the WPs in direct contact with magma.
5	NRC staff review of the VA identified "…unavailability of acceptable consequence models to support igneous activity risk assessment" as an issue.	NRC staff Review of VA (Paperiello 1999, p. 13)	The disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) summarizes the igneous consequence models for the Yucca Mountain site. The AMR demonstrates that the TSPA-SR consequence model is adequate for its intended purpose and is an improvement over that used in the TSPA-VA. The AMR presents the model assumptions, model parameter inputs, and the models used in the TSPA-SR of possible disruptions of the repository by igneous activity. The AMR is summarized in Section 3.1.5 of the Disruptive Events PMR.
6	NRC staff review observed that "Another key assumption of the TSPA-VA that is not supported by available information is that magma particle sizes or particle velocities are insufficient to entrain HLW fragments."	NRC staff Review of VA (Paperiello 1999, p. 14)	The disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) discusses assumptions for waste entrainment in a volcanic eruptive plume. Particle size distribution has been significantly changed to reflect revised interpretation from Argonne National Laboratory.
7	NRC staff review "…concludes that HLW particle sizes will be reduced substantially when exposed to the physical, thermal, and chemical environment associated with YM igneous events".	NRC staff Review of VA (Paperiello 1999, p. 14)	The disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) discusses assumptions regarding waste particle size. The AMR uses input from a calculation of waste particle sizes that supported the *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2000o). For TSPA-SR analyses that consider HLW particle sizes in the magmatic environment conclude that particle sizes would be smaller than those used in the TSPA-VA.

8	Dose consequences of magmatic intrusion pose an unacceptable risk. Greater reliance on engineered barriers or selection of an alternate site would better protect public health, safety, and the environment.	Letter from U.S. Senator from Maryland (Barrett 1998)	Disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* Section 4.2 (CRWMS M&O 2000l) provides some parameters needed by TSPA to calculate the dose consequences of volcanism. The event probability is a modified compilation of the PVHA expert elicitation's and was obtained from disruptive events AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b). The parameters are used within the TSPA model to calculate the dose per year for the critical group. Igneous consequence modeling is discussed in Section 3.1.5 of the Disruptive Events PMR. For the TSPA-SR the DOE is evaluating a system of natural characteristics and engineered elements that provide multiple, redundant barriers to the transport of radionuclides. Consequences of magmatic intrusion are being evaluated to determine the magnitude of the dose risk. Regulatory requirements preclude over-reliance on engineered barriers, and congress mandated characterization of only Yucca Mountain in the Nuclear Waste Policy Amendments Act of 1987.
9	Is there potential for hydrothermal upwelling of groundwater in response to igneous activity? (Szymanski: concern apparently based on fluid inclusion work that indicates presence of fluids at elevated temperatures; need information on ages of inclusions)	(NWTRB 1999, Chapter 2, pp. 19 to 21)	UZ PMR FEPs AMR *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2000n) provides the basis to screen out the issue of hydrothermal upwelling of groundwater in response to igneous activity for TSPA-SR. This issue is also addressed in part by FEP 1.2.10.01.00 in the *Features, Events, and Processes: Disruptive Events* AMR (CRWMS M&O 2000h) and discussed briefly in Section 3.2.4 of the Disruptive Events PMR.

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4. ADDRESSING NRC KTIs

The NRC has identified ten KTIs. Nine of these issues comprise technical questions that the NRC sees as major uncertainties. The tenth is a non-technical issue related to development of an EPA standard. Questions associated with these technical issues represent uncertainties that must be addressed in the Safety Analysis Report, which is part of the LA. The NRC staff has indicated that it plans to structure review of issues discussed in the PMRs within the framework of the KTIs as described in the IRSR for each KTI. Therefore, to facilitate potential NRC review of the PMRs and eventual NRC reviews of the TSPA-SR and the LA, this chapter discusses how the analyses and the one calculation supporting the disruptive events PMR support addressing KTI subissues.

4.1 SUMMARY OF THE NRC KTIs

As part of the review of site characterization activities, the NRC has undertaken an ongoing review of information on Yucca Mountain site characterization activities to allow early identification and resolution of potential licensing issues. The principal means of achieving this goal is through informal, pre-licensing consultation with the DOE. This approach attempts to reduce the number of, and to better define, issues that may be in dispute during the NRC licensing review, by obtaining input and striving for consensus from the technical community, interested parties, and other groups on such issues.

The NRC has focused pre-licensing issue resolution on those topics most critical to the postclosure performance of the potential geologic repository. These topics are called KTIs. Each KTI is subdivided into a number of subissues (DOE 1998c, Section 4.3.3). The KTIs are:

- Activities Related to Development of the EPA Standard
- Container Life and Source Term
- Evolution of the Near-field Environment
- Igneous Activity
- Radionuclide Transport
- Repository Design and Thermal Mechanical Effects
- Structural Deformation and Seismicity
- Thermal Effects on Flow
- Total System Performance Assessment and Integration
- UZ and SZ Flow Under Isothermal Conditions.

Identifying KTIs, integrating their activities into a risk-informed approach, and evaluating their significance for postclosure performance helps ensure that NRC's attention is focused on technical uncertainties that will have the greatest effect on the assessment of repository safety.

Early feedback among all parties is essential to define what is known, what is not known, and where additional information is likely to make a significant difference in the understanding of future repository safety. The IRSRs are the primary mechanism that the NRC staff uses to provide feedback to the DOE on the status of the KTI subissues. IRSRs focus on NRC acceptance criteria for issue resolution and the status of issue resolution, including areas of agreement or staff comments and questions. Open meetings and technical exchanges between

NRC and DOE provide additional opportunities to discuss issue resolution, identify areas of agreement and disagreement, and plans to resolve any disagreements.

KTIs are subdivided into a number of subissues. For most subissues, the NRC staff has identified technical acceptance criteria that the NRC may use to evaluate the adequacy of information related to the KTIs. The NRC has also identified two cross-cutting programmatic criteria that apply to all IRSRs related to the implementation of the QA program and the use of expert elicitation. The following sections provide a summary level discussion of the KTIs by subissues and a discussion of the specific NRC acceptance criteria.

This Disruptive Events PMR describes technical analyses that address subissue acceptance criteria associated with five of the KTIs, as described in their associated IRSRs. Table 4-1 lists these KTIs and their subissues. The KTIs and subissues that are directly addressed by information in this report are discussed in the following sections. Subissues addressed in this report are shown in italics in Table 4-1.

Discussions of the general manner in which disruptive events analyses and the calculation address the KTI subissue acceptance criteria is presented to aid in mapping these to the appropriate disruptive events analyses. Mapping of disruptive events AMR's and the calculation to acceptance criteria for the KTIs, for all IRSRs, is reserved for presentation in Section 4.7. In assessing how disruptive events analyses address IRSR acceptance criteria, it is important to note the effects of repository design on the issue being addressed. As the AMRs and the calculation supporting the Disruptive Events PMR were being developed, the repository design was evolving and underwent changes. The AMRs and calculation supporting this PMR were performed for a design with backfill and drip shields (CRWMS M&O 1999a). Subsequent evolution of the repository design has resulted in removal of backfill, realignment of drift azimuths and a shift in the coordinates of the repository footprint, the SRSL design (CRWMS M&O 2000z). Versions of the AMRs and calculation are to be prepared (as revisions or under the ICN process of AP-3.10Q) that perform recalculations to reflect the changed design. For future design changes, project management will determine whether the impact on disruptive events work warrants performing additional analyses or calculations. The Disruptive Events PMR is written in a manner that supports flexibility in the TSPA by assuming that concerns exemplified by NRC IRSR acceptance criteria, related to WPs, also apply to drip shields. The Disruptive Events PMR further assumes that, in the absence of backfill, impacts to drip shield performance in shielding WPs from water is of concern. Therefore, the following will show which AMRs and calculations directly address the acceptance criteria and comment on those that can be adapted to support addressing impacts to drip shields.

4.2 NRC KTI TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION

The objective of the NRC KTI Total System Performance Assessment and Integration is to "…describe an acceptable methodology for conducting assessments of repository performance and using these assessments to demonstrate compliance with the overall performance objective and requirements for multiple barriers" (NRC 2000, p. 3). The description of what TSPAs must consider includes disruptive events that could potentially breach the WPs and lead to radionuclide release into the geosphere.

Table 4-1. NRC IRSR KTIs

NRC KTI IRSRs	Subissues
[1]Total System Performance Assessment and Integration	* System Description and Demonstration of Multiple Barriers
	* Scenario analysis
	* Model abstraction
	Demonstration of the overall performance objective
[2]Igneous Activity	* Probability of future igneous activity
	* Consequences of igneous activity within the repository setting
[3]Structural Deformation and Seismicity	* Faulting
	* Seismicity
	Fracturing and structural framework of the geologic setting
	* Tectonics and crustal conditions
[4]Container Life and Source Term	Effects of corrosion processes on container lifetime
	* Effects of instability and initial defects on mechanical failure and container lifetime
	Rate of SNF radionuclide release from EBS
	Rate of HLW radionuclide release from EBS
	Effects of in-package criticality on WP and EBS performance
	* Effects of alternate EBS designs on container lifetime and radionuclide release from the EBS
[5]Repository Design and Thermal-Mechanical Effects	Implementation of an effective design control process within the overall QA program
	Implementation of an effective design control process within the overall QA program
	* Design of the geologic repository operations area for the effects of seismic events and direct fault disruption
	Thermal-mechanical effects on underground facility design and performance
	Design and long-term contribution of repository seals in meeting postclosure performance objectives

Sources: [1]NRC 2000; [2]Reamer 1999; [3]NRC 1999a; [4]NRC 1999b; [5]NRC 1999c

NOTE: *Subissues indicated by asterisk are directly addressed by disruptive events analyses. Addressing others receives indirect support or no support from these analyses.

TSPAs must consider the behavior of a complex engineered design and the FEPs typical of the geologic barrier, including coupled processes. Coupled processes include thermal, hydrologic, mechanical, and chemical processes coupled to each other in various combinations. This IRSR addresses integration of technical disciplines to ensure that transfer of information among disciplines and consideration of interrelationships among the processes are appropriately incorporated into the TSPA. This IRSR concentrates on the aspects of TSPA needed to build a safety case.

4.2.1 Subissues of the KTI Mapped to Disruptive Events Analyses and the Calculation

The subissues of this KTI that are addressed, at least in part, by the disruptive events AMRs and calculation are shown in Table 4-2. This PMR addresses the subissues as they appear in Revision 2 of the IRSR. Subissues were reworded, and new information, including NRC comments on the TSPA-VA, was added in Revision 2. Only Subissues 3 and 4 are discussed in detail in Revision 1 of the IRSR (NRC 1998d). Revision 2 of the IRSR updates the acceptance criteria and other aspects of Subissues 3 and 4. Revision 2 also reduces the number of subissues from five to four by placing the requirements for Subissue 5, transparency and traceability, within Subissue 2. Subissue 2 is renamed by adding the term "System Description" to become System Description and Demonstration of Multiple Barriers. Revision 2 leaves the development of acceptance criteria and review methods for Subissue 1 to later revisions. Therefore, discussion of that Subissue in this PMR is limited (NRC 2000, pp. 4 to 5). Detailed discussion of how Subissues 2, 3, and 4 are addressed by disruptive events analyses is presented in Sections 4.2.2, 4.2.3, and 4.2.4 of this PMR.

Table 4-2. IRSR KTI Total System Performance Assessment and Integration Subissues Addressed by Disruptive Events Analysis and Model Reports and Calculation

Total System Performance Assessment and Integration Subissue	Disruptive Events Analysis/Calculation
1. System Description and Demonstration of Multiple Barriers	All the disruptive events AMRs support addressing the traceability and transparency aspect of this subissue. No acceptance criteria at this time for the demonstration of multiple barriers aspect.
2. Scenario Analysis	[1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*; [2]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*; [3]*Features, Events, and Processes: Disruptive Events*; [4]*Characterize Eruptive Processes at Yucca Mountain, Nevada*; [5]*Dike Propagation Near Drifts;* [6]*Igneous Consequence Modeling for TSPA-SR*; [7]*Effects of Fault Displacement on Emplacement Drifts*; [8]*Fault Displacement Effects on Transport in the Unsaturated Zone*
3. Model Abstraction	[1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*; [2]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*; [3]*Features, Events, and Processes: Disruptive Events*; [4]*Characterize Eruptive Processes at Yucca Mountain, Nevada*; [5]*Dike Propagation Near Drifts;* [6]*Igneous Consequence Modeling for TSPA-SR*; [7]*Effects of Fault Displacement on Emplacement Drifts*; [8]*Fault Displacement Effects on Transport in the Unsaturated Zone,* [9]*Number of Waste Packages Hit by Igneous Intrusion*
4. Demonstration of Overall Performance	Overall performance is the result of the TSPA analysis itself, and cannot be addressed by individual AMRs. [10]All the Disruptive Events AMRs address some aspects of this subissue given the caveat stated above.

Sources: NRC 2000, p. 4; [1]CRWMS M&O 2000b; [2]CRWMS M&O 2000c; [3]CRWMS M&O 2000h; [4]CRWMS M&O 2000a; [5]CRWMS M&O 2000e; [6]CRWMS M&O 2000l; [7]CRWMS M&O 2000g; [8]CRWMS M&O 2000i; [9]CRWMS M&O 2000k

NOTE: [10] Preliminary information on the subissue indicates that these analyses address the objective of the subissue. No acceptance criteria exist at this time, and thus cannot be addressed.

Subissue 1, System Description and Demonstration of Multiple Barriers, has two main parts: (1) transparency and traceability and (2) demonstration of multiple barriers. Transparency and traceability, taken together, should result in an analysis that allows for adequate understanding of the approach and results of the TSPA and its supporting analyses and documentation. Section 4.2.2 contains a discussion of which disruptive events analyses address this aspect of the subissue. Acceptance criteria and other information describing demonstration of multiple barriers analysis were not included in Revision 2 of the IRSR and will be developed in a subsequent revision. Therefore, there is no discussion of how disruptive events analyses address this aspect of the subissue. For all subissues, Table 4-12 of this PMR contains mapping between acceptance criteria and disruptive events analyses and the calculation.

Subissue 2, Scenario Analysis, is concerned with identifying possible FEPs that could affect repository performance, assigning probabilities to them, and determining which can be excluded from TSPA. FEPs screening is considered a key factor in ensuring completeness of the TSPA. Section 4.2.3 contains a discussion of acceptance criteria for this subissue, which identifies the disruptive events analyses that support meeting the criteria.

Subissue 3, Model Abstraction, focuses on information and technical support requirements for development of abstracted models for TSPA including: (1) data used in development of conceptual approaches or process-level models that are the basis for abstraction to TSPA, (2) resulting abstracted models used by TSPA, and (3) overall performance of the repository system as estimated in TSPA. This subissue addresses the need for incorporation of numerous FEPs in an integrated manner to ensure a comprehensive TSPA. Section 4.2.4 contains a discussion of acceptance criteria for this subissue showing the disruptive events analyses that support meeting the criteria.

Subissue 4, Demonstration of the Overall Performance, is addressed by the complete TSPA and largely outside the scope of the Disruptive Events PMR. The subissue addresses "…calculation of the performance measure—consistent with parameter uncertainty, alternative conceptual models, and the treatment of processes and events" (NRC 2000, p. 142). As shown in Table 4-2, although acceptance criteria have yet to be developed, and no final analysis is implied here, the two disruptive events framework AMRs (CRWMS M&O 2000b, 2000c) that summarized expert elicitations discussed how those elicitations treated data that contributed to capturing parameter uncertainty and how the elicitations considered alternative conceptual models. The AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) demonstrated the methodology applied for scenario analysis of processes and events. Other disruptive events AMRs and the calculation address parameter uncertainty, alternative conceptual models, and scenario analysis.

For the four subissues just listed, the Total System Performance Assessment and Integration IRSR states that two programmatic and five technical acceptance criteria apply. These seven acceptance criteria also appear, with slightly different wording, in other IRSRs addressed by disruptive events analysis, and the manner in which they are addressed is the same. The manner in which the AMRs and calculation supporting the Disruptive Events PMR address acceptance criteria for all IRSRs is discussed in Section 4.7. The following discussion explains the issues raised by the Total System Performance Assessment and Integration IRSR and, in general, how disruptive events analyses are related to these issues.

4.2.2 How Total System Performance Assessment and Integration Subissue 1, System Description and Demonstration of Multiple Barriers, Is Addressed by Disruptive Events Analyses and Calculation

Subissue 1, System Description and Demonstration of Multiple Barriers, consists of two main parts: (1) transparency and traceability and (2) demonstration of multiple barriers (NRC 2000,

p. 9). Transparency means that readers of a PA can clearly understand what has been done, the results, and why the results are as they are, and it allows clear identification of ways to test the accuracy and reproducibility of results. Traceability means that there is a clear, traceable chain linking results to models, assumptions, and sources of data used to formulate the result.

The disruptive events analyses and calculation address acceptance criteria in most of the categories of concern for the transparency and traceability part of the subissue. The categories of concern and the analyses or calculation that address them are shown in Table 4-3.

For this part of the subissue, acceptance criteria are grouped into categories related to ensuring transparency and traceability of the TSPA calculation and its supporting documentation. Disruptive events AMRs and the calculation support meeting the acceptance criteria by providing documentation for the work underlying portions of the TSPA models, assumptions, data, and other information. Table 4-12 in this PMR provides a comparison between the specific acceptance criteria and the disruptive events analyses and the calculation that address them.

The TSPA documentation style, structure, and organization have acceptance criteria that include ensuring that the documents are written in a straightforward, understandable manner with ample definition of terminology that is used consistently. Acceptance criteria under this category also require that important assumptions are highlighted, and that the relationship between documents is clearly road mapped. All disruptive events documentation supports addressing these issues.

Table 4-3. IRSR KTI Total System Performance Assessment and Integration IRSR Subissue System Description and Demonstration of Multiple Barriers Categories of Concern Addressed by Disruptive Events Analyses and the Calculation

Category of Concern for Transparency and Traceability	**Disruptive Events Analysis/Calculation**
TSPA Documentation Style, Structure, And Organization	All disruptive events AMRs and the calculation
FEPs Identification and Screening	[1]*Features, Events, and Processes: Disruptive Events*
Abstraction Methodology	[2]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*;[3]*Fault Displacement Effects on Transport in the Unsaturated Zone*; [4]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*; [5]*Characterize Eruptive Processes at Yucca Mountain, Nevada*; [6]*Dike Propagation Near Drifts*; [7]*Igneous Consequence Modeling for TSPA-SR*
Data Use and Validity	All disruptive events AMRs and the calculation
Assessment Results	All disruptive events AMRs and the calculation
Code Design and Data Flow	Not addressed by disruptive events analyses and calculation

Sources: NRC 2000; [1]CRWMS M&O 2000h; [2]CRWMS M&O 2000c; [3]CRWMS M&O 2000i; [4]CRWMS M&O 2000b; [5]CRWMS M&O 2000a; [6]CRWMS M&O 2000e; [7]CRWMS M&O 2000l

The transparency and traceability of FEPs identification is the concern of the second category of acceptance criteria. Acceptance criteria require sufficient documentation for methods and criteria for screening decisions and require that relationships between similar FEPs are road mapped. Disruptive FEPs analysis provides support in this area for FEPs related to igneous activity, seismicity, and structural deformation.

Model abstraction methodology includes ensuring that assumptions concerning specific processes and the validity of data are transparent and traceable. Acceptance criteria also require that there is clear road mapping between conceptual features (like patterns of volcanic events) and the abstracted models and algorithms. Disruptive events AMRs that summarize the process models developed by expert elicitations and add data from the literature support addressing these acceptance criteria.

The transparency and traceability of data use and validity applies to data on the geologic processes and events and interactions between natural systems and the engineered systems that were documented in disruptive events AMRs and the calculation. Disruptive events documentation of data clearly shows the sources of values and distributions and documents their appropriateness for the intended use as well as road mapping to QA support for the data.

TSPA results are expected to show compliance with the overall performance objective. The TSPA documentation must include showing how the estimated performance is related to subsystem components with traceability to the applicable analyses that identify the FEPs, assumptions, input parameters and models underlying the subsystem components. Disruptive events analyses are part of the chain of traceability and support transparency for development of subsystem conceptual models. Disruptive events analyses do not support one of the acceptance criteria under this category, presentation of intermediate results.

The last category of acceptance criteria for this subissue, code design and data flow, is not supported by disruptive events analyses. The acceptance criteria relate directly to documentation of modules of the code and its supporting design documents.

See Table 4-12 in this PMR for a more detailed mapping between disruptive events AMRs and the calculation and acceptance criteria for this subissue.

4.2.3 How Total System Performance Assessment and Integration Subissue 2, Scenario Analysis, Is Addressed by Disruptive Events Analyses and Calculation

For Subissue 2, Scenario Analysis, the NRC states that it "…considers the process of identifying possible processes and events that could affect repository performance; assigning probabilities to categories of events and processes; and the exclusion of processes and events from the performance assessment…" and "…is a key factor in ensuring the completeness of a TSPA" (NRC 2000, p. 4). The IRSR defines scenario as the discrete plausible future evolution of the repository system during the period of regulatory concern and states that it includes: (1) a postulated sequence of events (or may be characterized by the absence of events) and (2) assumptions about initial and boundary conditions (NRC 2000, p. 18).

There are five acceptance criteria categories (see Table 4-4) for the scenario analysis subissue (NRC 2000, p. 18): (1) identification of an initial list of processes and events, (2) classification of processes and events, (3) screening this initial list of processes and events, (4) formation of scenario classes using the reduced set of processes and events, and (5) screening scenario classes. There are also technical acceptance criteria for these categories of concern (NRC 2000, pp. 19 to 29).

Table 4-4. IRSR KTI Total System Performance Assessment and Integration IRSR Subissue Scenario Analysis Categories of Concern Addressed by Disruptive Events Analyses and the Calculation

Category of Concern for Scenario Analysis	Disruptive Events Analysis/Calculation
Identification of an Initial Set of Processes and Events	[1]TSPA FEPs Database contains an initial list of comprehensive FEPs that cover the natural and engineered systems for the potential repository. For the disruptive events group of analyses the AMR [2]*Features, Events, and Processes: Disruptive Events* contains the set of FEPs analyzed.
Classification of Processes and Events	[2]*Features, Events, and Processes: Disruptive Events*
Screening of Processes and Events	[2]*Features, Events, and Processes: Disruptive Events;* [3]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada;* [4]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*
Formation of Scenarios	[2]*Features, Events, and Processes: Disruptive Events*
Screening of Scenario Classes	[2]*Features, Events, and Processes: Disruptive Events;* [3]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada;* [4]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*

Sources: NRC 2000;[1]CRWMS M&O 2000j; [2]CRWMS M&O 2000h; [3]CRWMS M&O 2000c;[4]CRWMS M&O 2000b

Scenario analysis documentation is an activity performed mainly in TSPA-SR activities outside of disruptive events analyses. As appropriate, the FEPs AMR in each PMR, including the Disruptive Events PMR, address applicable acceptance criteria for this subissue.

A description of the TSPA FEPs analysis process is contained in Section 2.1.4 of this PMR. The five categories of activities under the scenario analysis subissue are covered by the TSPA FEPs analysis process and are broadly explained in Section 2.1.4. Each group of analyses and calculations under a PMR includes an AMR that contains FEPs analyses specific to that PMR's area of interest. For disruptive events, the AMR is the *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h).

The category "Screening of Processes and Events" contains acceptance criteria requiring that screening arguments based on probability are consistent with site information and use probability values that come from well-documented sources. For that reason the two disruptive events AMRs that summarize the documents that are the source of probability values for igneous activity and for seismicity and structural deformation support addressing the acceptance criteria. The same situation applies to the category, "Screening of Scenario Classes."

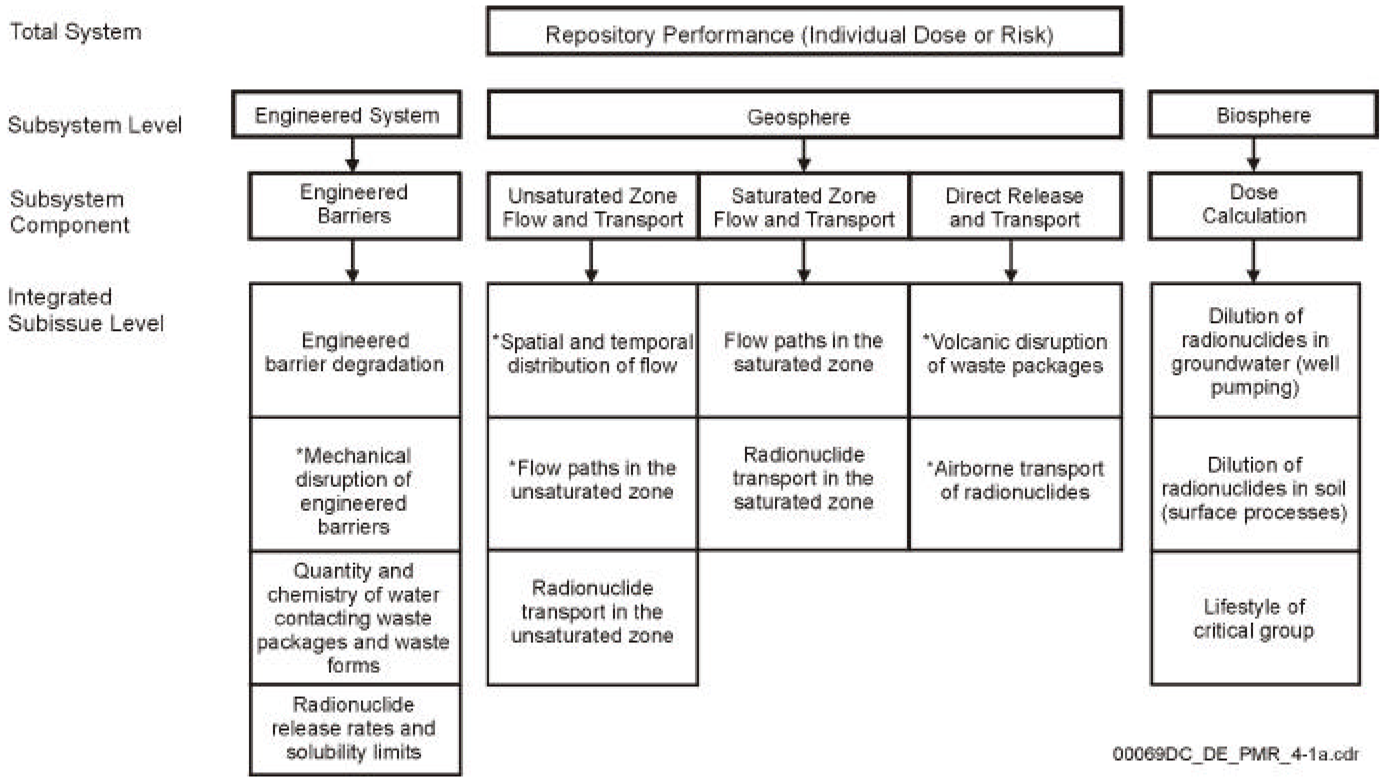
4.2.4 How Total System Performance Assessment and Integration Subissue 3, Model Abstraction, Is Addressed by Disruptive Events Analyses and Calculation

Subissue 3, Model Abstraction, is reviewed by the NRC staff using a hierarchical system represented by Figure 4-1. This figure shows (from bottom to top) how integrated subissues of repository subsystems are represented by abstractions that are further abstracted into successively larger units of subsystem analysis that, when combined, become the TSPA. Results of disruptive events analyses are used to support TSPA analyses representing disruptions of nominal performance and to address some of the integrated subissues as they apply to that type of analysis.

The disruptive events analyses and the calculation that address the integrated subissues (fourth level in Figure 4-1) for three of the five subsystem components of Subissue 3 are shown in Table 4-5. This table lists the three subsystem components and the integrated subissues addressed by disruptive events analyses, omitting those not addressed, and shows the AMR or calculation in which they are addressed.

As shown in Figure 4-1 and Table 4-5, only one of the integrated subissues, Mechanical Disruption of Engineered Barriers, for the subsystem component Engineered Barriers, is addressed by disruptive events analyses. For disruptive events analysis in this area, the focus is on events that lead to release via the groundwater pathway and the airborne pathway by compromising the waste isolation capacity of the WP. The two primary areas of analysis for disruptive events, (1) volcanism and (2) seismicity and structural deformation, present conceptual models and parameter values that describe geologic conditions that have the potential to adversely impact WP performance. The integrated subissue, Mechanical Disruption of Engineered Barriers, also maps to disruptive events analyses in the IRSR KTI, Container Life and Source Term, and is partially considered in the IRSRs for KTIs: Igneous Activity, Repository Design and Thermal-Mechanical Effects, and Structural Deformation and Seismicity (NRC 1999b, p. 4). Figure 4-1 also lists the integrated subissue volcanic disruption of WPs that is concerned with aspects of mechanical disruption of engineered barriers.

For the integrated subissue, Mechanical Disruption of Engineered Barriers, the effects of interest are seismicity, faulting, rockfall, and dike intrusion. Whether mechanical disruption/degradation of WPs is addressed by TSPA-SR depends on FEPs screening decisions presented in Table 2-2. There are FEPs listed in Table 2-2 associated with seismicity, faulting, and rockfall that are analyzed in the disruptive events FEPs AMR with regard to their potential effects on mechanical disruption of engineered barriers. Mechanical disruption of engineered barriers by magma from a dike intrusion, in the case of WPs, is not analyzed in FEPs screening, rather the assumption is made that WPs in contact with magma are damaged or compromised to the extent that they provide no protection. See the disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) for discussion of treatment of WPs in the magmatic environment.



Source: NRC 2000, Figure 3

NOTE: *Indicates integrated subissue is addressed by disruptive events analyses.

Figure 4-1. Hierarchical System for Reviewing Subissue 3, Model Abstraction

Table 4-5. IRSR KTI Total System Performance Assessment and Integration Subissue 3, Model Abstraction, Engineered Barrier Subsystem Component, Integrated Subissues Addressed by Disruptive Events Analyses and the Calculation

Engineered Barriers Subsystem Component Integrated Subissues	**Disruptive Events Analysis/Calculation**
Mechanical Disruption of Engineered Barriers	[1]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*; [2]*Effects of Fault Displacement on Emplacement Drifts*; [3]*Igneous Consequence Modeling for TSPA-SR*; [4]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*; [5]*Dike Propagation Near Drifts*; [6]*Characterize Eruptive Processes at Yucca Mountain, Nevada*; [7]*Number of Waste Packages Hit by Igneous Intrusion*; [8]*Features, Events, and Processes: Disruptive Events*
Unsaturated Zone Flow and Transport Subsystem Component Integrated Subissues	**Disruptive Events Analysis/Calculation**
Spatial and Temporal Distribution of Flow	[9]*Fault Displacement Effects on Transport in the Unsaturated Zone*
Flow Paths in the UZ	[9]*Fault Displacement Effects on Transport in the Unsaturated Zone*
Direct Release and Transport Subsystem Component Integrated Subissues	**Disruptive Events Analysis/Calculation**
Volcanic Disruption of WPs	[3]*Igneous Consequence Modeling for TSPA-SR*; [4]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*; [6]*Characterize Eruptive Processes at Yucca Mountain, Nevada*; [7]*Number of Waste Packages Hit by Igneous Intrusion*; [8]*Features, Events, and Processes: Disruptive Events*
Airborne Transport of Radionuclides	[3]*Igneous Consequence Modeling for TSPA-SR*; [8]*Features, Events, and Processes: Disruptive Events*

Sources: NRC 2000; [1]CRWMS M&O 2000c; [2]CRWMS M&O 2000g; [3]CRWMS M&O 2000l; [4]CRWMS M&O 2000b; [5]CRWMS M&O 2000e; [6]CRWMS M&O 2000a; [7]CRWMS M&O 2000k; [8]CRWMS M&O 2000h; [9]CRWMS M&O 2000i

The igneous intrusion groundwater transport analysis in the AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) also supports addressing the mechanical disruption subissue. The assumption was made that any WPs in contact with magma during an intrusive event were completely compromised, and all of the contents were available to be dissolved and transported in groundwater that flowed through the fractured basalt formed from the cooled magma. The amount of waste exposed was determined by calculation of the number of WPs hit using dike length inside the repository from the igneous activity framework AMR (CRWMS M&O 2000b), dike width from the eruptive processes AMR (CRWMS M&O 2000a), and distance of magma flow into drifts from the dike propagation AMR (CRWMS M&O 2000e). Transport of the waste exposed by the intrusive event was treated in the same manner as that for transport from other sources in the UZ flow model in the TSPA.

Analysis that supports addressing the subissue Mechanical Disruption of Engineered Barriers (by seismicity, faulting, and rockfall) is dependent on design elements, particularly the presence or absence of backfill and drip shields. Throughout this PMR, concern expressed in IRSRs about damage to WPs is inferred to mean that drip shields are also of concern when they are present in the design. The analyses supporting this Disruptive Events PMR were performed for a design that included backfill and drip shields, EDA II (CRWMS M&O 1999a) and a design without backfill, SRSL (CRWMS M&O 2000z). Depending on the design option, rockfall is a mechanism that has the potential to degrade performance by causing mechanical damage to the WP or drip shield that could result in accelerated corrosion of the WP, resulting in enhanced availability of wastes to the groundwater pathway. Seismically induced ground motion and faulting may have the potential to cause separation of drip shield overlaps and allow increased seepage to contact WPs, potentially accelerating corrosion. The AMR *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g) shows that the effects of direct fault displacements are insignificant given appropriate setbacks from active faults. Rockfall is not significant if backfill is present; but is analyzed for impacts to drip shield performance in the absence of backfill, and analyses have been done for impacts to WP performance in the absence of both backfill and drip shields. The AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) contained several FEPs screening arguments related to mechanical effects on WPs or drip shields that could result from ground motion or fault displacement.

As shown in Figure 4-1 and Table 4-5, two of the integrated subissues for the subsystem component UZ Flow and Transport are addressed by disruptive events analyses. The integrated subissues are (1) Spatial and Temporal Distribution of Flow and (2) Flow Paths in the UZ. The AMR *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i) addresses both integrated subissues by examining the effects fault displacement could have on fracture apertures in the area of the potential repository. The possibilities that fracture aperture changes could increase flow rates, change perched water distribution, or change the relative flux between fracture and matrix are examined in the AMR.

As shown in Figure 4-1 and Table 4-5, two of the integrated subissues for the subsystem component Direct Release and Transport are addressed by the Disruptive Events PMR supporting analyses. The integrated subissues are (1) Volcanic Disruption of WPs and (2) Airborne Transport of Radionuclides. The disruptive events AMRs and calculation assume that any WPs encountered by the conduit during a volcanic eruption event were completely compromised and all the contents were available to be transported in the eruptive column that exited the vent at the surface. The amount of waste exposed was determined by calculation of the number of WPs hit in various damage zones using the number, spatial distribution, and size of conduits impacting drifts (CRWMS M&O 2000k). Conduit parameters came from the igneous activity framework AMR (CRWMS M&O 2000b) and were supported by conduit diameter data from the eruptive processes AMR (CRWMS M&O 2000a). The software code ASHPLUME is suggested as a suitable code for modeling airborne transport as part of the TSPA-SR analysis (CRWMS M&O 2000l). The supporting parameters were developed by the AMR relating to igneous consequence modeling (CRWMS M&O 2000l).

4.3 NRC KTI IGNEOUS ACTIVITY

The Igneous Activity KTI was defined by the NRC as predicting the "…consequence and probability of igneous activity affecting the repository in relationship to the overall system performance objective" (Reamer 1999, p. 3). The Igneous Activity KTI comprises two subissues Probability and Consequences and their associated acceptance criteria (Reamer 1999). The Probability subissue focuses on the likelihood of future igneous activity intersecting the repository. The Consequences subissue focuses on examining the effects of an eruption in the vicinity of the repository. The integrated subissues (NRC 2000, Table 2) to which the igneous activity subissues map are listed below:

Subissue 1: Probability

- Maps to integrated subissues: Direct1, Volcanic Disruption of WPs

Subissue 2: Consequences

- Maps to integrated subissues: ENG2 Mechanical Disruption of Engineered Barriers, Direct1 (see description above), Direct2 Airborne Transport of Radionuclides, Dose2 Redistribution of Radionuclides in Soil, and Dose3 Lifestyle of the Critical Group.

Integrated subissues are the "...integrated processes, features, and events that could impact performance" (NRC 2000, p. 30). Integrated subissues apply to subissues for individual IRSRs, across all of the IRSRs, and illustrate the overlapping nature of the subissues from IRSR to IRSR.

Acceptance criteria developed by the NRC for each subissue describe the gauges that the NRC will use to determine the adequacy and acceptability of DOE's descriptions of natural FEPs related to each subissue. The subsections that follow provide mapping of disruptive events analyses and the calculation to the acceptance criteria for the two igneous activity subissues (probability and consequence). This subsection also provides discussion of important issues related to the acceptance criteria. Section 4.7 provides information on how the analyses and calculation support addressing the acceptance criteria.

4.3.1 Igneous Activity KTI Probability Subissue and Acceptance Criteria

The probability subissue includes definition of igneous events, determination of recurrence rates, and examination of geologic factors that control the timing and location of igneous activity. Nine acceptance criteria have been developed related to determining the probability of future igneous activity (Reamer 1999, pp. 15 to 16). Table 4-6 lists the Disruptive Events PMR supporting documents in which these criteria are addressed. Discussions in the following sections describe more specifically how the information in the Disruptive Events PMR and supporting documents meet the acceptance criteria. The Igneous Activity IRSR states that the DOE and the NRC have not yet reached agreement on the appropriate range of volcanic and intrusive probability estimates to use in PA (Reamer 1999, Section 5.1). Section 5.1 of the IRSR also states that the NRC considers the DOE preferred value of 1.5×10^{-8} per year as, at best, representing the low end of acceptable probability values. DOE analysis suggests that the choice of input parameters used by the NRC compared to those used in the PVHA logically places the highest NRC probability value at the extreme upper tail of a probability distribution (CRWMS M&O 2000b, Section 7).

Table 4-6. IRSR KTI Igneous Activity Probability Subissue Acceptance Criteria

Probability Acceptance Criterion	Disruptive Events Analysis/Calculation
1: The estimates are based on past patterns of igneous activity in the Yucca Mountain region.	[1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*; [2]*Characterize Eruptive Processes at Yucca Mountain, Nevada*
2: The definitions of igneous events are used consistently. Intrusive and extrusive events should be distinguished and their probabilities estimated separately.	Same as above
3: The models are consistent with observed patterns of volcanic vents and related igneous features in the Yucca Mountain region.	[1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*
4: Parameters used in probabilistic volcanic hazard assessments, related to recurrence rate of igneous activity in the Yucca Mountain region, spatial variation in frequency of igneous events, and area affected by igneous events are technically justified and documented by DOE.	[1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada;* [2]*Characterize Eruptive Processes at Yucca Mountain, Nevada;* [3]*Number of Waste Packages Hit by Igneous Intrusion;* [4]*Igneous Consequence Modeling for TSPA-SR*
5: The models are consistent with tectonic models proposed by NRC and DOE for the Yucca Mountain region.	[1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada;* [5]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*
6: The probability values used by DOE in PAs reflect the uncertainty in DOE's probabilistic volcanic hazard estimates.	[1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada;* [2]*Characterize Eruptive Processes at Yucca Mountain, Nevada*; [3]*Number of Waste Packages Hit by Igneous Intrusion*; [6]*Features, Events, and Processes: Disruptive Events*
7: The values used (single values, distributions, or bounds on probabilities) are technically justified and account for uncertainties in probability estimates.	Same as above and [7]*Dike Propagation Near Drifts*
8: If used, expert elicitations were conducted and documented using the guidance in the *Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program* [8] or other acceptable approaches.	[2]*Characterize Eruptive Processes at Yucca Mountain, Nevada*
9: The collection, documentation, and development of data and models have been performed under acceptable QA procedures, or if data was not collected under an established QA program, it has been qualified under appropriate QA procedures.	All disruptive events analyses and the calculation

Sources: Reamer 1999, pp. 15 to 16;[1]CRWMS M&O 2000b; [2]CRWMS M&O 2000a; [3]CRWMS M&O 2000k; [4]CRWMS M&O 2000l; [5]CRWMS M&O 2000c; [6]CRWMS M&O 2000h; [7]CRWMS M&O 2000e; [8]Kotra et al. 1996

NOTE: This statement precedes each probability criterion: "Estimates of the probability of future igneous activity in the YMR will be acceptable provided that:" (Reamer 1999, pp. 15 to 16).

The PVHA (CRWMS M&O 1996) and the analyses that build from the data provided by the PVHA experts, as described in AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b), provide the fundamental basis for the DOE probabilities used in PAs for SR documentation. The NRC uses a single value of 1×10^{-7} for the annual probability of volcanic disruption (Reamer 1999, Section 5.1). The NRC believes this value is reasonably conservative. However, the value does not represent the range of interpretations and uncertainties that the experts provided for characterizing the volcanic hazard at Yucca Mountain (see Section 2.1.2.2 of this PMR).

DOE plans to use the full distribution of the annual frequency of igneous intersection of a repository at Yucca Mountain, as determined from the elicitation of ten volcanism experts (CRWMS M&O 1996). This distribution represents the uncertainties in assessing the likelihood of such a disruptive event. As a probabilistic analysis, the TSPA requires a quantitative characterization of uncertainties. Any particular value of the distribution can be used in the TSPA (including the NRC's preferred estimate of 10^{-7} per yr.) to check for sensitivity. As described in the following sections, the DOE will test the sensitivity of the results to using NRC's preferred estimate.

The PVHA and supporting AMR documents meet the acceptance criteria outlined by the NRC in the IRSR. Specific examples are provided in the following discussions of each criterion.

4.3.1.1 Probability Acceptance Criterion 1

Probability Acceptance Criterion 1: The estimates [of probability] are based on past patterns of igneous activity in the Yucca Mountain region.

As discussed in the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*, conceptual models used in the PVHA are consistent with past patterns of igneous activity (CRWMS M&O 2000b, Section 6.3.3). The PVHA incorporates a range of temporal and spatial models that are based on the timing and distribution of past eruptive centers and volcanic activity in the Yucca Mountain region (CRWMS M&O 1996, Appendix E).

The Igneous Activity IRSR states that "It also is not clear why the 5-11 Ma volcanics were not considered by all experts to define spatial patterns or derive process models" (Reamer 1999, Section 4.1.1.3, p. 18). Petrologic data and 5-11 Ma centers were considered by all the PVHA experts in their assessments of the spatial distributions and recurrence (CRWMS M&O 1996). However, they were considered to provide poorer constraints on the locations and rate of future volcanism than data on younger volcanic centers. Therefore, they were given little or no weight in PVHA experts hazard models (CRWMS M&O 1996, Figure 3-62). In Section 4.1.3.3.1 of the Igneous Activity IRSR (Reamer 1999, p. 25), the NRC staff appear to agree with this assessment.

The NRC staff note that sufficient information exists to resolve this criterion and that they have no questions with regard to the material presented in the TSPA-VA related to this criterion (Reamer 1999, Section 5.1.1). However, the observations cited and discussed in the text immediately preceding this statement indicate that although the DOE has based probability estimates on past patterns of igneous activity in the Yucca Mountain region, the NRC still has concerns about the range of annual probabilities used for volcanic eruption release and igneous intrusion.

4.3.1.2 Probability Acceptance Criterion 2

Probability Acceptance Criterion 2: The definitions of igneous events are used consistently. Intrusive and extrusive events should be distinguished and their probabilities estimated separately.

The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* discusses the definitions and parameters of a volcanic event and the implications for probability calculations (CRWMS M&O 2000b, Section 6.3.2). All experts defined a volcanic event as a spatially and temporally distinct body of magma ascending from the mantle, forming a dike or system of dikes and, possibly, forming surface eruptions from one or more vents (also called volcanoes or eruptive centers). There were slight differences among the PVHA experts in the temporal and spatial parameters used to distinguish separate events. A volcanic event was represented mathematically in the PVHA hazard calculation by a point located at the expected midpoint along the length of the dike, or dike system, associated with the event. Although the PVHA considered volcanic events to possibly have an eruptive or extrusive (volcano) component associated with the intrusive component (dike), the output of the PVHA was an annual frequency of intersection of the repository footprint by an intrusive basaltic dike (CRWMS M&O 1996, Figure 4-32). The PVHA did not calculate the conditional probability that a dike intersecting the repository footprint would result in an extrusive volcanic eruption through the repository.

The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* provides an assessment of the eruptive probability that has been derived from the PVHA based on consideration of the length and orientation of the intersecting dike and the probability that an eruptive center forms within the repository footprint during future eruptions (CRWMS M&O 2000b, Sections 6.5.3.2, 7.0). Intrusive and extrusive events are clearly distinguished and their probabilities are calculated separately in the disruptive events scenarios for consequence analysis, as described in the AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l, Section 6.0).

The PVHA and NRC model parameters that pertain to event definition are not equivalent. The PVHA intersection probability represents the probability of a dike intersection. The PVHA experts did not calculate the probability of a conduit intersecting the repository, nor did they calculate the number and location of conduits that could occur on a dike or dike system. The calculation of those probabilities was performed under the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*, as mentioned above, for the two designs (EDA II and SRSL) (CRWMS M&O 2000b). For the DOE calculation of the probability of a conduit intersecting the repository (conditional on dike intersection), the distribution of conduits along a dike was modeled based on (1) PVHA expert output and observed vent spacing in the Yucca Mountain region, (2) the assumption that the location of eruptive centers is uniformly distributed along the length of the dike, and (3) the assumption that the presence of the repository openings (emplacement drifts) has no effect on where a conduit will form (i.e., a conduit can form on a dike in a location within or outside of the repository). The result of this calculation is that the probability of an eruption (conduit) within the repository is always less than the probability of dike intersection, by a factor of approximately 2 (CRWMS M&O 2000b, Section 6.5.3.2). The NRC preferred probability value, for intersection of the repository by a volcanic event, is for a volcano through the repository and is based on the interpretation that every intersection of a vent alignment with the repository footprint results in an eruption through the repository (Reamer 1999, Section 4.1.6.3.2, p. 57) and the assumption that the probability of intersection by shallow intrusive events that do not erupt is necessarily higher, possibly by a factor of 2 to 5 (Reamer 1999, Section 4.1.6.3.4). Combining the NRC approach (assuming that every intersection results in at least one conduit through the repository) with the DOE approach results in the probability of an eruption within the repository being 0.77 times the dike intersection probability (CRWMS M&O 2000b).

In the PVHA definition of a volcanic event, the number of intrusive and extrusive events in the Yucca Mountain region is generally considered to be similar. Dikes that rise to depths of <0.5 to 1 kilometers below ground level are expected to erupt at some point along the length of the dike. A multiplication factor was included in the PHVA assessments to account for undetected intrusive events (those that did not reach the surface or are presently obscured). This "hidden event" factor typically resulted in a multiplier of 1.1 to 1.2 (CRWMS M&O 1996, Figure 3.62).

The NRC assumption that all vent alignment intersections result in eruption through the repository implies that intrusive events that intersect the repository and do not erupt represent entirely separate events. The NRC assumption of higher intrusion probabilities in the Yucca Mountain region is based on analogy to the San Rafael volcanic field on the western Colorado Plateau, where an extensive system of shallowly intruded dikes is well exposed (Delaney and Gartner 1997). No attempt is made in Delaney and Gartner (1997) to estimate the frequency of temporally discrete intrusive versus eruptive events. As discussed in the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b, Section 6.3.2.1), while data and discussion presented in Delaney and Gartner (1997) have been used to argue that intrusive events without an eruptive component occur 2 to 5 times more frequently than intrusive events with an eruptive component, an alternative interpretation is that the intrusion/extrusion ratio is closer to 1. This alternative interpretation is more consistent with the geologic record of the Yucca Mountain region, as demonstrated at the Paiute Ridge analog site.

In summary comments on this criterion, the NRC expressed more confidence in data supporting estimates for the probability of a volcanic eruption event (extrusive) than for an igneous intrusion, and observed they wanted to see completion of consequence analysis before deciding that further work on igneous intrusion was warranted. The staff repeated the observation that use of both a 1.5×10^{-8} and a 10^{-7} annual probability for volcanic eruption release in calculations would be acceptable. The staff had no other questions with this criterion at the time of the issuance of the IRSR (Reamer 1999, p. 133).

4.3.1.3 Probability Acceptance Criterion 3

Probability Acceptance Criterion 3: The models are consistent with observed patterns of volcanic vents and related igneous features in the Yucca Mountain region.

A detailed explanation of conceptual models of volcanism and the formulation of probability models is provided in the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b, Section 6.3.3). The discussions in Section 6.3.3 emphasize that the conceptual model of volcanism (i.e., how and where magmas form, and what processes control the timing and location of magma ascent through the crust to form volcanoes) has fundamental impacts on how probability models are formulated and the consequent results of probability models. The Igneous Activity IRSR notes that good agreement exists on the basic patterns of basaltic volcanism in the Yucca Mountain region, and the staff has no questions regarding the material presented in TSPA-VA related to this criterion (Reamer 1999, Section 5.1.3, p. 133).

In summary comments on this criterion, the NRC staff stated that good agreement exists with regard to observations regarding patterns of volcanic vents and related igneous features and consideration of these features in current probability models. The staff had no questions with the material presented in the TSPA-VA related to this criterion (Reamer 1999, p. 133).

4.3.1.4 Probability Acceptance Criterion 4

Probability Acceptance Criterion 4: Parameters used in probabilistic volcanic hazard assessments related to recurrence rate of igneous activity in the Yucca Mountain region, spatial variation in frequency of igneous events, and area affected by igneous events are technically justified and documented by DOE.

As noted in the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b, Section 6.3), the technical basis and documentation of the alternative models and parameter values that were used in the PVHA are documented in CRWMS M&O (1996).

The review method for this criterion outlined in the Igneous Activity IRSR states that "…the kernel function must be estimated and used to deduce a probability density function for spatial recurrence rate of volcanism" (Reamer 1999, Section 4.1.4.3.2, p. 34). The Igneous Activity IRSR states that "Estimation of spatial volcanism [in the Yucca Mountain region] must then rely on patterns of past activity, which is done using kernel models" (Reamer 1999, Section 4.1.4.4, p. 41). DOE agrees that kernel models are an appropriate method for estimating spatial recurrence of igneous activity. The volcanism experts who provided inputs to the PVHA used kernel models, as well as other models, to establish the range of spatial recurrence rates. The experts generally felt that the use of a single type of model did not adequately capture the uncertainties in defining those inputs.

The Igneous Activity IRSR also states that "Staff conclude that the distribution of sparse events does not provide an accurate basis to conclude that spatial recurrence rate within the repository boundary is zero or a low background value" (Reamer 1999, Section 4.1.4.4, p. 41). The PVHA experts do not "conclude" that the spatial rate of volcanic events within the repository boundary is zero or near zero. The PVHA experts addressed the issue of limited data by developing distributions for the spatial recurrence rate of volcanic events. Some of these distributions result in finite probabilities for very low rates in the repository area. These low rates cannot be precluded by the limited data available. One purpose of the PVHA was to express the full range of uncertainty in quantifying the hazard.

Section 4.1.4.3.1 and Section 5.1.4 of the Igneous Activity IRSR (Reamer 1999) describe concerns that significant amounts of information developed after the PVHA elicitation have not been addressed. DOE agrees that new and relevant information available after the completion of the expert elicitation needs to be assessed. In accordance with DOE procedures for conducting and documenting expert elicitation projects, the relevance of these data with respect to the assessments of the Expert Panel has been and will continue to be assessed using methods such as sensitivity analyses. The DOE is monitoring new data and plans to incorporate significant new data into future technical and licensing documents.

Post-elicitation studies by the NRC staff (Stamatakos et al. 1997; Connor et al. 1997) provided evidence to support the likelihood of greater volume for a volcanic center in the Crater Flat field and an additional igneous center in the Amargosa Valley. Sensitivity studies showed that these new data did not significantly impact the results of the PVHA (CRWMS M&O 2000b, Section 6.3.1.6).

A review of other new data identified in the Igneous Activity IRSR (e.g., Wernicke et al. 1998; Earthfield Technology 1995; Magsino et al. 1998) suggests they will not significantly affect the PVHA results. The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b, Section 6.4) provides a discussion of more recent geodetic data (Savage et al. 1999) and geologic data that do not support the hypothesis that the Yucca Mountain region is currently in a period of anomalous strain rate that would increase the volcano recurrence rate, as suggested by Wernicke et al. (1998, p. 2099). Section 6.3.1.6 discusses the evidence for additional buried volcanic centers and the significance to PVHA results. As noted in this section, the aeromagnetic data used by Earthfield Technology (1995) have been shown to be incomplete and mislocated. The most reliable and detailed data available for magnetic anomalies in the Yucca Mountain region are presented in Connor et al. (1997) and Magsino et al. (1998). Significant results from these studies have been incorporated into the sensitivity analysis described above.

In summary comments on this criterion, the NRC staff observed that sufficient evidence exists to technically justify parameters discussed in this acceptance criterion and present a compilation of their data for these parameters (Reamer 1999, Appendix A). The staff also stated that "…new data from Wernicke et al. (1998) and Earthfield Technology (1995) does not warrant a significant revision of recurrence rates used in NRC probability models." However, they state that the new information could significantly affect recurrence rates used in DOE probability models (CRWMS M&O 1996). The staff summarize by saying that "If DOE would provide analysis which address (*sic*) the effects that inclusion of the above information has on overall probability values NRC questions related to this criterion would be resolved" (Reamer 1999, p. 134).

4.3.1.5 Probability Acceptance Criterion 5

Probability Acceptance Criterion 5: The models are consistent with tectonic models proposed by the NRC and DOE for the Yucca Mountain region.

The PVHA experts used a variety of spatial and temporal models that were consistent with tectonic models for the Yucca Mountain region. The PVHA project (CRWMS M&O 1996) was structured to ensure that the experts were familiar with the full range of tectonic models and hypotheses being advocated by technical specialists both within and outside the YMP. The PVHA thus meets this criterion.

A conceptual framework for the probability calculations, based on PVHA outputs and subsequent studies, is presented in the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b, Section 6.3.3). This framework accounts for deep (mantle) and shallow (structural control) processes that influence volcanic event distribution in the Yucca Mountain region. The framework presented in this AMR emphasizes the close correlation between the distribution of volcanic events and areas of crustal extension and faulting in the Yucca Mountain region, and within this context, the appropriateness of volcanic source zone boundaries defined in the PVHA (CRWMS M&O 2000b, Section 6.4.2).

The Igneous Activity IRSR uses the phrase "…utilizing the source zone models that preclude volcanoes from forming at the repository site, as was done repeatedly in Geomatrix" (Reamer 1999, Section 4.1.8.3). Source zone models presented in the PVHA do not preclude volcanic events at the repository site. No models developed by the experts resulted in a zero probability of volcanic events at the site. The deep crustal structural domain may place some spatial constraints on the location of a deep source zone for the magma, but these constraints do not apply in the shallow crust. Magma that is constrained to originate deep below Crater Flat may still produce kilometers-long dikes in the shallow crust that can cross the repository footprint and impact the repository. The deep crustal structure has no effect on where the dikes go in the shallow crust (only where magma is coming from). They can cross an imaginary surface projection of the deep structural boundaries.

The NRC states in the Igneous Activity IRSR "Much of the confusion regarding volcanism source zones could be resolved if the relationships between volcanism and structure were considered mechanistically and in light of mapped structural features" (Reamer 1999, Section 4.1.5.3, p. 43). A mechanistic model relating mantle melting and lithospheric extension has recently been proposed for the Yucca Mountain region by NRC staff (Reamer 1999, Section 4.1.5.3.2) and, additionally, is used as the geologic basis for weighting spatial density models based on crustal density variations across the Yucca Mountain region (Reamer 1999, Section 4.1.6.3.3). The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* provides arguments against this approach (CRWMS M&O 2000b, Section 6.3.3). This AMR notes that, as formulated, a finite-element model that calculates lateral pressure changes in the Yucca Mountain region based on upper crustal density variations is a poor predictor of volcano distribution in the Yucca Mountain region.

The NRC probability model relies on spatial density functions weighted by crustal density (Reamer 1999, Section 4.1.6.3.3). Significantly, this probability model is the basis for calculating the highest probability value for a volcanic eruption within the repository boundary, 9×10^{-8} (Reamer 1999, p. 61), which is the value (rounded up to 10^{-7}) that the NRC plans to use for the purposes of PA (Reamer 1999, p. 61). This probability model results in an approximately two-fold increase in the intersection probability compared to unweighted spatial density models (CRWMS M&O 2000b, Section 6.3.3). As discussed in the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*, the results of this probability model also depend to a large extent on dike lengths that are inconsistent with the geologic record of the Yucca Mountain region (CRWMS M&O 2000b, Section 6.3.2).

In terms of probability calculations, the southwestern Crater Flat volcanic source zones represent local regions of higher event frequency, while northeastern Crater Flat, including Yucca Mountain, falls within areas with lower event frequencies (Reamer 1999). According to the intersection probability model used in the PVHA, two mechanisms can generate a disruptive event at Yucca Mountain:

- An event is generated within a local source zone (higher probability event) to the west of Yucca Mountain and has the appropriate location and dike characteristics (length and azimuth) to intersect the potential repository.

- An event is generated within the regional background zone (lower probability event) and intersects the repository.

Because the intersection probability at the potential repository includes components of both mechanisms, the intersection probability calculated for the repository should reflect spatial event frequencies that lie between local source zone values and regional background values, consistent with the results of the PVHA, and appropriate for a site that lies outside of a local volcanic source zone but near enough to be affected by dikes generated within the source zone. This is illustrated by the spatial density maps shown in Figure 3-2.

In summary comments on this criterion, the NRC staff stated that DOE analyses in the TSPA-VA for the probability-weighted location of magma rising from a deep source zone showed that these deep source zones are more likely to be located in Crater Flat than directly below the repository. The staff commented that this was not reasonably conservative and that the model used by the NRC was more consistent with seismic reflection, gravity, and magnetic data. The staff concluded that "The staff's question regarding this criterion is, therefore, the ability of DOE to reconcile the volcanological models with the tectonic models and geophysical data" (Reamer 1999, p. 134).

4.3.1.6 Probability Acceptance Criterion 6

Probability Acceptance Criterion 6: The probability values used by DOE in PAs reflect the uncertainty in DOE's probabilistic volcanic hazard estimates.

Using expert elicitation for the PVHA satisfied the goal of properly and completely characterizing uncertainty in the assessment of volcanic hazard (CRWMS M&O 1996). The resulting PVHA probability distribution provides a reasonable representation of the knowledge and uncertainty about the volcanic hazard at the potential Yucca Mountain site. The probability distribution reflects the broad range of experience and judgment of experts from within and outside the YMP. The PVHA results provide direct input into an assessment of occurrence probability for disruptive events in the TSPA. In accordance with the objective of this criterion, the full PVHA probability distribution has been and will continue to be used in the TSPA and consequence analyses for SR and LA.

The Igneous Activity IRSR describes how new models developed in the TSPA-VA propose that the average annual probability of volcanic disruption of the repository site is around 6×10^{-9}, with an upper bound around 2×10^{-8}. NRC staff analyses indicate these low values do not accurately account for the long history of recurring basaltic volcanism around Yucca Mountain but are more representative of the annual probability of a volcano erupting randomly within the Western Great Basin province (Reamer 1999, Section 5.1.6, p. 135). The Igneous Activity IRSR further describes how, for the purpose of PA, the NRC will assume the value of 10^{-7} per yr. for volcanic disruption of the potential repository site (Reamer 1999, Section 4.1.6.4, p. 61).

The 1×10^{-7} per yr. probability is a high percentile in the NRC parameter distributions (defined as ranges). Analysis at 1×10^{-7} per yr. was included in the TSPA-VA analysis as a sensitivity ("what if") calculation separate from the distribution defined by the PVHA. This is documented in Volume 10 of the Technical Basis Document that supports the TSPA-VA, Volume 3 (CRWMS M&O 1998b, p. 10-53, Figure 10-48). The DOE will continue to use the full probability distribution derived from the PVHA elicitation to calculate the component of the expected annual dose resulting from igneous activity for the TSPA-SR. An annual frequency value of 10^{-7} will be in the range of values included in the analyses.

In summary comments on this criterion, NRC staff state that uncertainty in probability models consists of components measuring precision (parameter uncertainty) and accuracy (model uncertainty). No specific statements about DOE parameter uncertainty are made and the accuracy of TSPA-VA models is not evaluated (Reamer 1999, p. 135).

4.3.1.7 Probability Acceptance Criterion 7

Probability Acceptance Criterion 7: The values used (single values, distributions, or bounds on probabilities) are technically justified and account for uncertainties in probability estimates.

As noted in the discussion under Probability Acceptance Criterion 6, the focus and motivation for the PVHA was the characterization, quantification, and documentation of the knowledge and uncertainty in the assessment of volcanic hazards at Yucca Mountain (CRWMS M&O 1996). A deliberate process was followed in facilitating interactions among the experts, in training them to express their uncertainties, and in eliciting their interpretation. Through multiple workshops and interactions the experts were reminded that full documentation of uncertainty in both models used to represent the key physical controls on volcanism and the parameter values used in the models was the objective of the study. All inputs related to the spatial and temporal aspects of the hazard assessment, including uncertainties and full distributions, are technically justified and documented in the PVHA in full compliance with this criterion.

The DOE will continue to use the full probability distribution derived from the PVHA model, as updated to account for the current repository footprint, to calculate the component of the expected annual dose resulting from igneous activity for the TSPA-SR. The NRC's preferred annual frequency value of 10^{-7} will be in the range of values included in the analyses.

In summary comments on this criterion, the NRC staff repeated the observation that use of both "the DOE probability value" and a 10^{-7} annual probability for volcanic eruption release in calculations would mean that "…the NRC would have a basis to resolve its questions with this acceptance criterion" (Reamer 1999, p. 135).

4.3.1.8 Probability Acceptance Criterion 8

Probability Acceptance Criterion 8: If used, expert elicitations were conducted and documented, using the guidance in the Branch Technical Position on Expert Elicitation (Kotra et al. 1996) or other acceptable approaches.

The probability hazard assessment elicitation conducted for the PVHA (CRWMS M&O 1996) is consistent with the guidance in the Branch Technical Position on Expert Elicitation. Additional discussion of the controls on the collection, documentation, and development of data and models associated with estimation of the volcanic hazard are provided in the PVHA (CRWMS M&O 1996). In recognition of their general concurrence with this conclusion, the NRC staff has agreed as stated in Section 5.1.8 of the Igneous Activity IRSR (Reamer 1999) to give the PVHA elicitation results the appropriate level of consideration in review of licensing documents. Concerns of the NRC staff regarding the appropriate level of review of new data (Reamer 1999, Section 5.1.8) are being addressed as outlined above under Probability Acceptance Criterion 4.

In summary comments on this criterion, the NRC staff state that the expert elicitation supporting the PVHA (CRWMS M&O 1996) was consistent with Branch Technical Position guidelines (Kotra et al. 1996) and state that they would give the elicitation the "appropriate level of consideration in review of licensing documents" (Reamer 1999, p. 136). The staff also state that there were new data not addressed at the time of the TSPA-VA that would affect volcano recurrence rates or source-zone definitions significantly and that in developing probability values for an LA the DOE would need to reconcile the new data with the PVHA results. The staff concludes: "This would resolve NRC questions related to this criterion" (Reamer 1999, p. 136).

4.3.1.9 Probability Acceptance Criterion 9

Probability Acceptance Criterion 9: The collection, documentation, and development of data and models have been performed under acceptable QA procedures, or if data was not collected under an established QA program, it has been qualified under appropriate QA procedures.

The data used for the PVHA expert elicitation are described in detail in the PVHA report (CRWMS M&O 1996). All of the data outputs from the PVHA are fully qualified because they were determined using the expert elicitation process. The manner in which this criterion is addressed by all disruptive events AMRs and the calculation is discussed in Section 4.7.1 of this PMR, in the paragraph on Programmatic Criterion P1 of the Total System Performance Assessment and Integration IRSR.

In summary comments on this criterion, the NRC staff state that the TSPA-VA used unqualified data, codes, and models for igneous activity analysis, but noted that it was not designed to be a Quality Controlled document. The staff express concern over the limited time remaining to qualify data and have formed a task force to monitor DOE progress in the area of QA (Reamer 1999, p. 136).

4.3.1.10 Additional Comments Relevant to Probability Acceptance Criteria

For the Igneous Activity Probability Acceptance Criteria the following observations are made in the IRSR, and these observations are included here to provide insights regarding NRC technical questions that may exist for these criteria.

In the introduction to discussion of probability issues, the NRC staff comment that "DOE and NRC have not yet reached agreement on the appropriate range of volcanic and intrusive probability estimates to use in performance assessment." (Reamer 1999, p. 131). The NRC staff state that annual probabilities of from 10^{-7} to 10^{-8} for volcanic activity (eruption release) from intersection of the potential repository bound the range of "credible models," and that they will use 10^{-7} in their PA. The staff also observe that there is inadequate data for the Yucca Mountain region to arrive at a meaningful probability for igneous intrusive events, but based on analog studies they assume that intrusive events have a 2 to 5 times higher probability of occurrence compared to a volcanic eruption release event. The NRC staff also state that DOE use of an annual probability value of 1.5×10^{-8} in calculations and of a calculation showing the change in overall risk from using the NRC-preferred value of 10^{-7} "…should remove any substantive differences between the NRC and DOE on this subissue" (Reamer 1999, p. 132).

Some apparent differences between description of volcanism by DOE and NRC are not related to geologic properties but are more the result of emphasis, with the NRC emphasizing the consequences when extremes of the range of possibilities are compounded. The DOE probabilistic TSPA approach includes these extremes but considers the mean to be the most characteristic value representing expected conditions. The effects of extreme conditions represented in the tails of parameter distributions, including those presented in alternative conceptual models, are included in the TSPA-SR through sampling of parameter value distributions. Consequences of the combinations of unfavorable conditions are shown by the range of outcomes from the multiple realizations.

4.3.2 Igneous Activity KTI Consequences Subissue and Acceptance Criteria

The consequences subissue includes definition of the physical characteristics of igneous events, determination of eruption characteristics for Quaternary basaltic volcanism in the Yucca Mountain region, models of the effect of the geologic repository setting on igneous processes, evaluation of waste package/waste form-magma interactions, and determination of volcanic deposit characteristics relevant to the consequences of igneous activity. Seven acceptance criteria have been developed related to evaluating the consequences of future igneous activity. The technical criteria address the characteristics of basaltic volcanic eruptions that would be expected in the Yucca Mountain region, the dynamics of the eruptive column, the effects of the repository on eruption characteristics, waste package/waste form-magma interactions, and description of parameters needed to allow reasonable dose conversion models to be developed (Reamer 1999, Section 4.2, p. 68). Table 4-7 lists the Disruptive Events PMR analyses in which these criteria are addressed. Discussions in this section describe more specifically how the information in the Disruptive Events PMR and supporting documents addresses the individual igneous activity consequence acceptance criteria.

Table 4-7. IRSR KTI Igneous Activity Consequences Subissue Acceptance Criteria

Consequences Acceptance Criterion	Disruptive Events Analysis Calculation
1: The models are consistent with the geologic record of basaltic igneous activity within the Yucca Mountain region[1].	[1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*; [2]*Characterize Eruptive Processes at Yucca Mountain, Nevada*; [3]*Igneous Consequence Modeling for TSPA-SR*.
2: The models are verified against igneous processes observed at active or recently active analog igneous systems and reflect the fundamental details of ash-plume dynamics.	[1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*; [2]*Characterize Eruptive Processes at Yucca Mountain, Nevada*; [3]*Igneous Consequence Modeling for TSPA-SR*.
3: The models adequately account for changes in magma ascent characteristics and magma/rock interactions brought about by repository construction.	[1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*; [2]*Characterize Eruptive Processes at Yucca Mountain, Nevada*; [3]*Igneous Consequence Modeling for TSPA-SR*; [4]*Number of Waste Packages Hit by Igneous Intrusion*; [5]*Dike Propagation Near Drifts*.
4: The models account for the interactions of basaltic magma with engineered barriers and waste forms.	[2]*Characterize Eruptive Processes at Yucca Mountain, Nevada*; [3]*Igneous Consequence Modeling for TSPA-SR*; [4]*Number of Waste Packages Hit by Igneous Intrusion*; [5]*Dike Propagation Near Drifts*.
5: The parameters are constrained by data from Yucca Mountain region igneous features and from appropriate analog systems such that the effects of igneous activity on waste containment are not underestimated.	[3]*Igneous Consequence Modeling for TSPA-SR*; [4]*Number of Waste Packages Hit by Igneous Intrusion*; [6]*Waste Package Behavior in Magma*; [7]Fuel particles sizes for physically degraded spent fuel following a disruptive event through the repository.
6: If used, expert elicitations were conducted and documented using the guidance in the *Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program*[8] or other acceptable approaches.	Not addressed by disruptive events analyses or calculation.
7: The collection, documentation, and development of data and models has been performed under acceptable QA procedures, or if data was not collected under an established QA program, it has been qualified under appropriate QA procedures.	All disruptive events analyses and calculation.

Source: Reamer 1999; [1]CRWMS M&O 2000b; [2]CRWMS M&O 2000a; [3]CRWMS M&O 2000l; [4]CRWMS M&O 2000k; [5]CRWMS M&O 2000e; [6]CRWMS M&O 1999b; [7]CRWMS M&O 2000o; [8]Kotra et al. 1996

4.3.2.1 Consequences Acceptance Criterion 1

Consequences Acceptance Criterion 1: The models are consistent with the geologic record of basaltic igneous activity within the Yucca Mountain region.

A detailed explanation of conceptual models of volcanism and the formulation of probability models is provided in the igneous framework AMR (CRWMS M&O 2000b, Section 6.3.3). The discussions in Section 6.3.3 of the AMR emphasize that the conceptual model of volcanism (i.e., how and where magmas form, and what processes control the timing and location of magma ascent through the crust to form volcanoes) has fundamental impacts on how probability models are formulated and the consequent results of those probability models. The AMR discussions include detailed descriptions of the history and characteristics of basaltic igneous activity in the Yucca Mountain region.

The NRC staff maintains that analyses using physical conditions attendant to violent strombolian eruptions would resolve NRC questions under this criterion (Reamer 1999, Section 5.2.1).

Analyses in support of TSPA-SR assume that all eruptions include a violent strombolian phase, and the ash cloud dispersal code ASHPLUME uses parameter values typical of a violent strombolian eruption for all iterations (CRWMS M&O 2000l, Section 5.2.1). However, the TSPA-SR geologic conceptual model of the actual characteristics of a typical strombolian eruption in the Yucca Mountain region is that it would go through varying phases including violent, effusive, and moderate eruption. Data from analog sites provide a basis for estimating probability distributions related to the dimensions and geometry of volcanic conduit diameter for a plausible future formation of a new volcano during the repository lifetime (CRWMS M&O 2000a, Section 5). As discussed in Section 5.2.1 of AMR *Igneous Consequence Modeling for TSPA-SR*, uncertainty associated with the nature of the violent phase, including its duration (the length of time that the volcanic eruption is occurring) and the volume (the amount of material that is expelled from the volcano during the event) of material erupted, is included in the analysis through the development of a distribution function characterizing uncertainty in the volume of erupted material (CRWMS M&O 2000l). The distribution for erupted volume is developed from observations of the total volume of material erupted from analog volcanoes, regardless of the nature of the eruption. An assumption to be used with the software code ASHPLUME (CRWMS M&O 2000l) in support of the calculation to be used for SR assumes the full volume of material participates in the violent phase of the eruption.

Information in the AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) indicates that there is little justification for assuming that violent phases dominate during strombolian eruption (CRWMS M&O 2000a, Section 6.3). Citing the Lathrop Wells volcano as an example, Section 6.3 describes features that indicate that only some stages of its eruptions were violent strombolian. Thick stubby aa flows are identified as indications of short duration, high mass flux effusive eruption. Mounds of partly welded, coarse spatter and bombs record phases of more typical strombolian activity. Other volcanoes in the Yucca Mountain region are described as less well preserved than the Lathrop Wells volcano, but these other volcanoes nevertheless apparently exhibit a similar range of eruptive styles at individual centers. Hence, the NRC staff's focus on violent strombolian activity seems to reflect a level of conservatism in their analyses.

4.3.2.2 Consequences Acceptance Criterion 2

Consequences Acceptance Criterion 2: The models are verified against igneous processes observed at active or recently active analog igneous systems and reflect the fundamental details of ash-plume dynamics.

Assumptions regarding the use of data from analog sites as a basis for estimating probability distributions for various input parameters within the igneous consequence model are outlined in Section 5 of the AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a, Section 5). The proposed use of ASHPLUME (CRWMS M&O 2000l) to model a volcanic eruption at Yucca Mountain is considered reasonable for this event (CRWMS M&O 2000l, Section 6.1). As stated in the Igneous Activity IRSR, the NRC staff "…conclude that the modified tephra-dispersal model of Suzuki (1983) provides an acceptable approach to calculating tephra-fall deposits from violent strombolian volcanoes and would appear to provide an acceptable approach to calculating high level waste-contaminated tephra fall deposits" (Reamer 1999, p. 139). They note that the DOE has adopted the modified tephra-dispersal model of Suzuki for use in the TSPA-VA and have no current questions regarding the implementation. The NRC acceptance of the underlying Suzuki model for modeling volcanic events coupled with well-supported estimates for the input values to the model provides a reasonable first order estimate of the igneous eruptive event, and thus this model is recommended in the disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* for use in the TSPA-SR (CRWMS M&O 2000l, Section 6.1).

4.3.2.3 Consequences Acceptance Criterion 3

Consequences Acceptance Criterion 3: The models adequately account for changes in magma ascent characteristics and magma/rock interactions brought about by repository construction.

The dynamics of magma ascent are summarized in the AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a, Section 6.3) and are discussed in Section 3.1.2 of this report. The AMR states that the dynamics of magma ascent are largely functions of magma viscosity and volatile content, and the analysis provided in the AMR describes the roles of various parameters that are related to magma viscosity and volatile content, including:

- Magma ascent rate below volatile exsolution
- Volatile exsolution and fragmentation
- Velocity as a function of depth above the exsolution depth
- Eruption duration.

The potential effects of repository construction on magma ascent characteristics and magma/rock interactions are discussed in the AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e). The topics examined in the AMR (in a qualitative manner) include waste container temperature increases caused by the flow of magma in a blind (closed-end) drift, steady-state gas flow down a drift to interact with waste containers, and physical interaction of the pressure pulse from a dike resulting in displacement of waste containers and other drift contents. A qualitative assessment was done of the interaction of a magma-generated crack that leads the dike with the stress-altered region around the repository. Section 3.1.3 of this Disruptive Events PMR contains more details on the scope and results of this report.

4.3.2.4 Consequences Acceptance Criterion 4

Consequences Acceptance Criterion 4: The models account for the interactions of basaltic magma with engineered barriers and waste forms.

In the Igneous Activity IRSR, the NRC staff takes issue with the TSPA-VA assumptions regarding WPs and entrainment of waste during volcanic eruptions (Reamer 1999, Section 5.2.4). The IRSR states that the TSPA-VA does not demonstrate that WP survivability can be assumed. The IRSR also states that, because the DOE safety case appears to be based on WP and waste form resilience during igneous events, additional data and models will need to provide a reasonable basis that WPs can indeed withstand exposure in an actively erupting volcanic conduit and that high-level waste will not be substantially entrained by such an eruption. The IRSR concludes that DOE modeling assumptions are not substantiated by information in the literature or independent DOE studies and will not meet acceptance criteria presented in the IRSR.

Subsequent to TSPA-VA, analyses were conducted by DOE regarding these issues. In addition to the analysis of dike propagation near drifts (CRWMS M&O 2000e) described under consequence Acceptance Criterion 3, analyses were also completed of the number of WPs contacted by an igneous intrusion (CRWMS M&O 2000k), WP behavior in magma (CRWMS M&O 1999b), and fuel particle sizes for physically degraded spent fuel following a disruptive event through the repository (CRWMS M&O 2000o).

The TSPA-SR model is based on assumptions regarding the behavior of waste, WPs, and other components of the EBS in a magmatic environment that are relatively more conservative than those used in the TSPA-VA. As noted in the AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) for designs with or without backfill, any WPs, drip shields, and other components of the EBS that are partially or completely intersected by an eruptive conduit or immediately adjacent to an intrusive dike are assumed to be damaged to the point that they provide no protection for the waste (CRWMS M&O 2000l, Section 5.3). All waste within WPs that are intersected by an eruptive conduit is available to be entrained in the eruption. Actual conditions in eruptive magmatic environments and the response of the WPs and other components of the EBS are uncertain. WPs directly intersected by an eruptive conduit may be subjected to a range of conditions characteristic of rapid pyroclastic flow during violent strombolian eruptions, or to less extreme conditions during less violent eruptions. For the no-backfill design (SRSL), the AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) describes a scenario in which WPs in a drift intersected by a dike, but not immediately adjacent to the dike, are exposed to pressure that can cause the welded endcaps to develop failures. In this AMR, the zone of damage for WPs immediately adjacent to the dike is called Zone 1, and the zone within the intersected drift, but farther away from the dike, is called Zone 2. For the igneous intrusion groundwater release scenario, all waste material in WPs contacted by magma during an igneous intrusion is assumed to be available for incorporation in the UZ transport model, dependent on solubility limits and the availability of water.

4.3.2.5 Consequences Acceptance Criterion 5

Consequences Acceptance Criterion 5: The parameters are constrained by data from Yucca Mountain region igneous features and from appropriate analog systems such that the effects of igneous activity on waste containment and isolation are not underestimated.

The discussions of Consequences Acceptance Criteria 1 through 3 above describe how information in various AMRs demonstrates how parameters are constrained by data from Yucca Mountain region igneous features. The constraints provide reasonable limits on parameters such that the effects of igneous activity on waste containment and isolation are not likely to be underestimated. The Igneous Activity IRSR concludes that there is substantial agreement between the NRC and DOE on this criterion, and that most differences are not significant (Reamer 1999, Section 5.2.5, p. 141). However, the IRSR notes that the modeling assumptions presented in the TSPA-VA related to wind speed and directions must either be modified or supported by data. The IRSR states that the wind velocity and direction used in TSPA-VA were chosen to minimize the dose at 20 km south. It states that these wind conditions are not applicable to the elevations at which the plume exists. The IRSR cites data for wind speed of approximately 6 m/s at an elevation of 2 km from the land surface. The IRSR also states that wind speeds increase to approximately12 m/s at altitudes of 4 km (Reamer 1999, p. 88) and notes this is a reasonably conservative value to use in dose modeling. The IRSR also concludes that a "reasonably conservative" assumption is that the winds continually blow to the south.

Probability distributions for wind speed and direction are provided in Sections 6.1.2.7 and 6.1.2.8, respectively, of AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l). The values used by the DOE are based on wind speed and wind direction data representing current climatic conditions (CRWMS M&O 2000l, Sections 6.1.2.7 and 6.1.2.8). The parameter values used by the NRC apparently reflect a worst-case scenario.

4.3.2.6 Consequences Acceptance Criterion 6

Consequences Acceptance Criterion 6: If used, expert elicitations were conducted and documented, using the guidance in the Branch Technical Position on Expert Elicitation (Kotra et al. 1996) or other acceptable approaches.

The acceptance criteria for this consequence are identical to the discussion presented in Section 4.3.1.8.

4.3.2.7 Consequences Acceptance Criterion 7

Consequences Acceptance Criterion 7: The collection, documentation, and development of data and models have been performed under acceptable QA procedures, or if data were not collected under an established QA program, they have been qualified under appropriate QA procedures.

The acceptance criteria for this consequence are identical to the discussion presented in Section 4.3.1.9.

4.4 NRC KTI STRUCTURAL DEFORMATION AND SEISMICITY

The scope of the IRSR KTI Structural Deformation and Seismicity "…includes the geologic features, events, processes (FEPs) and conditions in and around the candidate repository that result from tectonic activities (except igneous activity, which is the subject of a separate KTI) that may affect or do affect evaluation of long-term-performance" (NRC 1999a, p. 1).

The report "…ensures that (1) all significant issues related to tectonics, seismotectonics, faults, and fractures are identified and adequately characterized; and (2) their significance is sufficiently understood, fully considered, and appropriately used to evaluate long-term performance…" (NRC 1999a, p. 1).

There are four subissues for the KTI Structural Deformation and Seismicity (NRC 1999a, p. 1). Revision 2 of the Total System Performance Assessment and Integration IRSR (NRC 2000, Table 2) includes mapping between the Structural Deformation and Seismicity IRSR subissues and the integrated subissues. The KTI subissues are listed below, along with an explanation of what they address and notation of the integrated subissue to which they map:

1. **Faulting**–This subissue is concerned with determination of the viable models of faults and fault displacements at Yucca Mountain.

   - Maps to integrated subissues: ENG2 Mechanical Disruption of Engineered Barriers and Direct1 Volcanic Disruption of Waste Packages (Explanation of Direct1: EBS elements already failed by volcanic disruption cannot be failed again by corrosion [NRC 2000, Figure 13]).

2. **Seismicity**–This subissue is concerned with determination of the viable models of seismic sources and seismic ground motions at Yucca Mountain.

   - Maps to integrated subissues: ENG2 (see description above) and UZ1 Spatial and Temporal Distribution of Flow.

3. **Fracturing and Structural Framework**–This subissue is concerned with determination of the viable models of fractures and structural controls of flow at Yucca Mountain.

   - Maps to integrated subissues: ENG2 (see description above), ENG3 Quantity and Chemistry of Water Contacting the Waste Packages and Waste Forms, UZ1 Spatial and Temporal Distribution of Flow, UZ2 Flow Paths in the UZ, UZ3 Radionuclide Transport in the UZ, SZ1 Flow Paths in the SZ, and SZ2 Radionuclide Transport in the SZ.

4. **Tectonic Framework of the Geologic Setting**–This subissue is concerned with determination of the viable tectonic models and crustal conditions at Yucca Mountain.

   - Maps to integrated subissues: ENG2, SZ1, and Direct1 (see descriptions above).

The statement is made that the scope of the IRSR also includes structural deformation and seismicity-initiated effects on waste containment and isolation and repository design for the preclosure period and flow and transport in the postclosure period and will be included in subsequent reports (NRC 1999a, p. 1). The IRSR states that the topic of repository design and preclosure performance will be addressed through comments on topical reports that cover this subject and that this topic is covered in the Repository Design and Thermal-Mechanical Effects IRSR (NRC 1999c). The Structural Deformation and Seismicity IRSR also states that it is through the Repository Design and Thermal-Mechanical Effects IRSR that "…the effects of earthquake-induced rockfall onto WPs [waste packages]…" is investigated (NRC 1999a, p. 8). This revision of the Structural Deformation and Seismicity IRSR only considers postclosure issues.

4.4.1 Disruptive Events Analyses and Calculation That Address the KTI Subissues

The Structural Deformation and Seismicity IRSR states that there is a set of generic acceptance criteria, presented in the Total System Performance Assessment and Integration IRSR, that apply to all IRSRs (discussed in Sections 4.3.1 and 4.3.2 in this PMR). They include topics such as QA and model uncertainty. The list of generic acceptance criteria in the Seismicity and Structural Deformation IRSR is a little different from that in the Total System Performance Assessment and Integration IRSR. Generic Criteria 1 through 5 in the Structural Deformation and Seismicity IRSR (NRC 1999a, pp. 18 to 20) correspond to Technical Criteria 1 through 5 in the Total System Performance Assessment and Integration IRSR (NRC 2000, p. 32), and the Total System Performance Assessment and Integration IRSR Programmatic Acceptance Criteria P1 and P2 (NRC 2000, p. 8) correspond to Generic Acceptance Criteria 6 and 7, respectively, in the Structural Deformation and Seismicity IRSR (NRC 1999a, pp. 20 to 21). These generic criteria are addressed at a general level in the same way for all disruptive events analyses and the calculation. The discussion for how each of these seven criteria are addressed (or not addressed) by disruptive events analyses would be the same for all four subissues and would be repetitive without providing new information. See Sections 4.3.1 and 4.3.2.4 in the Total System Performance Assessment and Integration discussion for this information. In instances where the discussion of the generic acceptance criteria includes a specific technical issue that is addressed specifically by disruptive events analyses, a discussion of how the disruptive events analysis addresses the issue will be provided.

In the Total System Performance Assessment and Integration flow down diagram showing the integrated subissues (Figure 4-1), Seismicity and Structural Deformation KTI subissues are relevant to five of them: (1) Mechanical Disruption of Engineered Barriers, (2) Spatial and Temporal Distribution of Flow (in the UZ), (3) Flow Paths in the Unsaturated Zone Distribution of Mass Flux Between Fracture and Matrix (in the UZ), (4) Volcanic Disruption of Waste Packages, and (5) Airborne Transport of Radionuclides (NRC 2000, Figure 3). Integrated subissue 3 is listed because of the topic of disruptive events AMR *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i), which is discussed in Section 3.2.2 of this PMR. The other three are mentioned in the Structural Deformation and Seismicity IRSR in relation to abstracting faulting into the TSPA, which is discussed in the next paragraph. The contribution of disruptive events analyses to other topics in the flow down diagram is discussed in Section 4.3 of this PMR. Details of the subissues for Structural Deformation and Seismicity and how disruptive events analyses address supporting them is discussed in the following text and three tables. The KTI Structural Deformation and Seismicity presents each of the four Structural Deformation and Seismicity subissues in the form of an associated question, and components are listed for each subissue (NRC 1999a).

For the Faulting subissue, the associated question is: "What are the viable models of faults and fault displacements at Yucca Mountain?" (NRC 1999a, p. 8). In the Structural Deformation and Seismicity IRSR, faults are discussed in conjunction with fracturing and the structural and tectonic framework of the geologic setting. The IRSR states that faults and faulting should be abstracted into PA codes through the integrated subissues identified in Figure 4-1: Mechanical Disruption of Engineered Barriers, Volcanic Disruption of Waste Packages, and Structural Control on Flow (Spatial and Temporal Distribution of Flow [in the UZ]) (NRC 2000, Figure 3). NRC review of DOE analyses of mechanical disruption of WPs will receive input from the

Structural Deformation and Seismicity IRSR in two ways: (1) evaluating the probability of faulting through drifts, estimating the averaged annualized number of WPs sheared by this faulting, and the incremental changes to expected annual dose from this Disruptive Event; and (2) proposing a prudent and reasonably conservative range of fault zone characteristics and fault displacement hazard parameters necessary for the Repository Design and Thermal-Mechanical Effects KTI to investigate the effects of earthquake-induced rockfall onto WPs (NRC 1999a, p. 8). The Structural Deformation and Seismicity IRSR is also concerned with (1) adequacy of set back distance and (2) models of groundwater flow where fracture permeability in and around faults may be an important parameter (NRC 1999a, p. 8). Fault and faulting input related to volcanic disruption of WPs supports the Igneous Activity IRSR investigation of the flow of magma through fault zones. In the Structural Deformation and Seismicity IRSR, faults are investigated in regard to their potential to act as conduits or barriers to the flow of water, vapor, magma, or heat (NRC 1999a, p. 10). The possibility of seismicity inducing existing faults to slip, or initiating new faults, is a part of the seismicity subissue that is also covered in the faulting subissue (NRC 1999a, p. 12).

Table 4-8 shows which disruptive events analyses address components of the faulting subissue. A discussion of each component follows the table.

Table 4-8. IRSR KTI Structural Deformation and Seismicity Subissue Faulting Components Addressed by Disruptive Events Analysis and Model Reports and Calculation

Subissue Faulting Components	Disruptive Events Analysis/Calculation
Fault Displacement Hazard	[1] *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*; [2] *Effects of Fault Displacement on Emplacement Drifts*; [3] *Fault Displacement Effects on Transport in the Unsaturated Zone*
Faulting Causing WP Failure	[4] *Features, Events, and Processes: Disruptive Events*
Faulting Exhuming WPs	[4] *Features, Events, and Processes: Disruptive Events*
Probability and Consequences (risk) of Faulting Directly Rupturing WPs	[1] *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*; [4] *Features, Events, and Processes: Disruptive Events*

Sources: NRC 1999a, p. 3; [1]CRWMS M&O 2000c; [2]CRWMS M&O 2000g; [3]CRWMS M&O 2000i; [4]CRWMS M&O 2000h

The Fault Displacement Hazard component was addressed in the PSHA (Wong and Stepp 1998) and is described in Section 2.1.3.2 of this PMR. The disruptive events framework AMR cited in Table 4-8 explained the process involved in the elicitation and summarized the results of this study. The disruptive events FEPs screening AMR provided screening arguments to support the conclusion that both potential fault displacement that sheared a WP and WPs being exhumed by fault displacement are very unlikely events (CRWMS M&O 2000h, Table 3, FEP 1.2.02.03.00). Screening arguments for the FEP “Faulting” (FEP 1.2.02.02.00) cover “faulting exhuming waste packages.”

The discussion of Generic Acceptance Criterion 5, Integration, for faulting requires that: “Incorporation of faulting models and parameters into TSPA models adequately includes important design features, physical phenomena, coupling and relies on consistent and appropriate assumptions throughout the abstraction process” (NRC 1999a, p. 20). As indicated in Table 4-8, conclusions from the two AMRs, which address the effects of fault displacement on the emplacement drifts (CRWMS M&O 2000g, Section 7) and on transport in the UZ (CRWMS M&O 2000i, Section 7), support including or excluding modeling of physical phenomena associated with fault displacement in the TSPA-SR.

For the Seismicity subissue, the associated question is: "What are the viable models of seismic sources and seismic motion at Yucca Mountain?" (NRC 1999a, p. 11). Vibratory ground motion associated with an earthquake could potentially damage facilities, including drifts, WPs, and drip shields. Rockfall in emplacement drifts could lead to premature breach of WPs (NRC 1999a, pp. 11 to 12). The IRSR states that the likelihood of earthquakes and their consequences should be abstracted into PA codes through the integrated subissues (Figure 4-1): Mechanical Disruption of Engineered Barriers (either the induced rockfall, secondary faulting, or repeated vibratory ground motion) and Fracture Dilation and Redistribution of Local Stress Field Affecting Flow (Spatial and Temporal Distribution of Flow [in the UZ]). Consequence assessment of rockfall is investigated by the Repository Design and Thermal-Mechanical Effects IRSR with the Structural Deformation and Seismicity IRSR providing information on "…input parameters including the seismic hazard curve and the distribution of fractures used to calculate the size of rockfall blocks" (NRC 1999a, p. 12). Other issues mentioned in the IRSR under the Seismicity subissue include direct damage to WPs by ground motion causing shaking or rolling and changes in the flow of groundwater caused by "seismic pumping." Both of these issues have been addressed by the disruptive events FEPs screening AMR (CRWMS M&O 2000h, Table 3, FEPs 1.2.03.02.00, 1.2.03.01.00, 1.2.01.01.00).

The PSHA study addressed the seismic and fault displacement hazard and produced hazard curves for both ground motion and fault displacement (Wong and Stepp 1998). The PSHA process considered Type 1 faults in its analysis and outputs. Type 1 faults are defined as "…faults or fault zones subject to displacement and of sufficient length and location that they (1) may affect repository design and performance of SSCs important to safety, containment, or waste isolation, and (2) may provide significant input to models used in the design or assessment of…" SSCs (NRC 1999a, p. 36). The disruptive events seismic framework AMR cited in Tables 4-8 and 4-9 describes the elicitation process and summarizes the results of the PSHA. Tables 4-8 and 4-9 show which disruptive events analyses address components of the Seismicity subissue.

For the fracturing and structural framework subissue, the associated question is: "What are the viable models of fractures at Yucca Mountain?" (NRC 1999a, p. 13). The IRSR states that fractures are important as potential pathways for water, vapor, heat, and possibly magma, and they play a role in drift stability. Disruptive events analyses did not specifically address the components of this subissue: (1) fracture data and models and (2) fracturing and structural framework of the geologic setting. However, the disruptive events analysis *Fault Displacement Effects on Transport in the Unsaturated Zone* used the UZ 3-D flow model to show that change in fracture aperture caused by fault displacement does not have a significant effect on flow in the UZ (CRWMS M&O 2000i, Section 7).

Table 4-9. IRSR KTI Structural Deformation and Seismicity Subissue Seismicity Components Addressed by Disruptive Events Analysis and Model Reports and Calculation

Subissue Seismicity Components	Disruptive Events Analysis/Calculation
Seismic Hazard	[1]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*; [2] *Features, Events, and Processes: Disruptive Events*
Type 1 Faults (part of seismic source characterization)	[1]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*; [2]*Features, Events, and Processes: Disruptive Events*
Ground Motion	[1]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada;* [2]*Features, Events, and Processes: Disruptive Events*
Probabilistic Seismic Hazard Methodology and Results of the PSHA	[1]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada*

Sources: NRC 1999a, p. 3; [1]CRWMS M&O 2000c; [2]CRWMS M&O 2000h

For the tectonics subissue, the associated question is: "What are the viable tectonic models at Yucca Mountain?" (NRC 1999a, p. 13). Tectonic models are seen as prerequisites to understanding Quaternary events and processes of importance during the regulatory time period. Tectonic FEPs mentioned in the Structural Deformation and Seismicity IRSR include (1) range-bounding or primary faults (such as Solitario Canyon), (2) earthquakes associated with primary and other faults, (3) basaltic volcanism, and (4) crustal extension rates caused by ongoing plate tectonics (NRC 1999a, p. 14). In addition, the observation is made that tectonic strain is the "…principal crustal condition of interest to seismotectonic hazard and volcanic hazard analysis…" (NRC 1999a, p. 80).

The components of the tectonics subissue are: viable tectonic models, DOE's preferred tectonic models, DOE's geologic framework models, and crustal strain at Yucca Mountain (NRC 1999a, p. 3). Table 4-10 shows which disruptive events analyses address components of the tectonics subissue. A discussion of the components follows the table.

Table 4-10. IRSR KTI Structural Deformation and Seismicity Subissue Tectonics Components Addressed by Disruptive Events Analysis and Model Reports and Calculation

Subissue Tectonics Components	Disruptive Events Analysis/Calculation
Viable Tectonic Models	Evaluated by PSHA. Disruptive Events analyses contribute to feedback as models are analyzed, but do not address directly.
DOE's preferred tectonic models	DOE does not have a preferred tectonic model.
DOE's geologic framework models	Geologic framework models developed through PSHA and PVHA. Disruptive Events analyses use the models, but do not address directly.
Crustal strain at Yucca Mountain	Site characterization activities address this issue. Disruptive Events analysis [1]*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* addresses new data in this area.

Sources: NRC 1999a, p. 3; [1]CRWMS M&O 2000b

Seismic source characterization experts considered and evaluated all viable tectonic models for Yucca Mountain in the PSHA assessment (as noted in Table 4-10, tectonic models were an integral part of the PSHA). Disruptive events analyses address the effects of faulting and seismicity FEPs and evaluate whether they should be included or excluded from TSPA-SR. These issues are addressed in the AMRs: *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h); *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i); and *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g). In the Disruptive Events PMR, Section 3.2.4 contains a discussion of the disruptive events FEPs that address faulting and seismicity and information on how the two other disruptive events AMRs address these FEPs. The Criterion 5 of the subissue supports determination of what models are necessary for TSPA-SR: "Incorporation of tectonic models into PSHA, Probabilistic Volcanic Hazards Assessment (PVHA) and TSPA adequately includes major structural features, physical phenomena, and coupling important to design and performance and relies on consistent and appropriate assumptions throughout the abstraction process" (NRC 1999a, p. 82).

One of the components implies an incorrect assumption: the DOE does not have a "preferred" tectonic model. For the PSHA, all viable tectonic models evaluated in the seismic source characterizations provided the basis for the ground motion and fault displacement hazard curves. The disruptive events AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b, Section 6.4) addresses several publications that present data developed after the PVHA that could impact interpretation of the geologic framework. One of these studies (Wernicke et al. 1998) presented data that suggested that previous estimates of strain rate near Yucca Mountain were underestimated and that this could have caused under-estimation of the volcanic hazard. A subsequent, more comprehensive study by Savage et al. (1999) indicates that the strain rate at Yucca Mountain, after the removal of local and regional fault effects, is not significant at the 95 percent confidence level. See Section 6.4 of the disruptive events AMR for a more detailed discussion (CRWMS M&O 2000b).

4.5 NRC KTI CONTAINER LIFE AND SOURCE TERM

The primary issue addressed in the Container Life and Source Term IRSR is "…adequacy of the engineered barrier subsystem (EBS) design, to provide reasonable assurance that containers will be adequately long-lived, and radionuclide releases from the EBS will be sufficiently controlled, such that container design and packaging of SNF and high-level waste glass will make a significant contribution to the overall repository performance" (NRC 1999b, p. 3). The IRSR focuses on containers and waste forms as primary engineered barriers but also considers enhancements such as backfill and drip shields. Analyses supported by the Disruptive Events PMR are linked to Container Life and Source Term subissues regarding performance of containers when disruptive events, or associated processes, compromise their integrity and possibly accelerate (beyond the nominal case) the rate of exposure of their contents.

4.5.1 Disruptive Events Analyses and Calculation That Address the KTI Subissues

The principal components of the subissues for the KTI in the Container Life and Source Term IRSR have been reformatted from Revision 1 (NRC 1998a) to Revision 2 (NRC 1999b, p. 4, Figure 1). Revision 2 of the Total System Performance Assessment and Integration IRSR (NRC 2000, Table 2) presents mapping between the Container Life and Source Term IRSR subissues and the integrated subissues. The subissues are listed below along with an explanation of what they address and notation of the integrated subissue to which they map, and the principal components of the subissues are shown in Figure 4-2:

1. The effects of corrosion processes on the lifetime of the containers. This subissue relates to the adequacy of DOE's consideration of the effects of corrosion processes on the lifetime of the containers (NRC 1999b, p. 20).

   - Maps to integrated subissues: ENG1 Degradation of Engineered Barriers, ENG2 Mechanical Disruption of Engineered Barriers, ENG3 Quantity and Chemistry of Water Contacting the Waste Packages and Waste Forms, and Direct1 Volcanic Disruption of Waste Packages.

2. The effects of phase instability of materials and initial defects on the mechanical failure and lifetime of the containers. This subissue relates to the adequacy of DOE's consideration of container materials stability and mechanical failure. Disruptive events, such as seismic activity, volcanism, and faulting may promote premature failure of the containers through different processes (NRC 1999b, p. 22).

   - Maps to integrated subissues: ENG1, ENG2, and Direct1 (see descriptions above).

3. The rate at which radionuclides in SNF are released from the EBS through the oxidation and dissolution of spent fuel. This subissue relates to the adequacy of DOE consideration of the effect of the rate of degradation of SNF on the subsequent release of radionuclides and the rate of release from the EBS (NRC 1999b, p. 24).

   - Maps to integrated subissues: ENG3 (see description above) and ENG4 Radionuclide Release Rates and Solubility Limits.

4. The rate at which radionuclides in high-level waste glass are released from the EBS. This subissue relates to the adequacy of DOE's consideration of the effects of degradation of HLW glass, taking into account the rate of degradation and its effect on the rate of radionuclide releases from the EBS (NRC 1999b, p. 26).

   - Maps to integrated subissues: ENG3 and ENG4 (see descriptions above).

5. The effect of in-package criticality on WP and performance. This subissue addresses whether DOE has sufficiently analyzed the effects of potential in-package nuclear criticality on repository performance during the repository operations period, and over the postclosure time frame of interest (NRC 1999b, p. 28).

   - Maps to integrated subissues: ENG2 and ENG4 (see descriptions above).

Subsystem: **Engineered System**

Primary Issue: Adequacy of EBS design to provide long-term containment and limited releases

Subissues	Effects of corrosion processes on container lifetime	*Effects of instability and initial defects on mechanical failure and container lifetime	Rate of SNF radionuclide release from EBS	Rate of HLW glass radionuclide release from EBS	Effects of in-package criticality on WP and EBS performance	Effects of alternate EBS designs on container lifetime and radionuclide release
Components of Subissues	Dry air oxidation	Thermal embrittlement of carbon steel overpack	SNF types	Long-term corrosion of HLW glass	Preclosure criticality	*Backfill
	Humid-air corrosion and uniform aqueous corrosion	Thermal stability of Alloy 22 overpack	Radionuclide inventory	Secondary minerals formation	Postclosure criticality	Ceramic coating
	Passive corrosion of resistant alloy	Initial defects	Dry-air oxidation	Natural analog studies	Criticality potential of all waste types	Embrittlement of titanium drip shield
	Localized corrosion		Gaseous release	Colloids and radionuclide transport		Corrosion of titanium drip shield
	Stress corrosion cracking		Aqueous dissolution of SNF			*Environmental cracking of titanium drip shield
	Hydrogen embrittlement		Solubility controlled radionuclide release			
			Secondary minerals and colloids			
			Cladding			

Source: NRC 2000, Figure 3

NOTE: *Indicates subject is addressed by disruptive events analysis.

Figure 4-2. Principal Components Container Life and Source Term Subissues

6. The effects of alternate EBS design features on container lifetime and radionuclide release from the EBS. This subissue is designed to address the effects of alternate EBS design features, such as backfill, drip shields, and ceramic coatings, on container lifetime and radionuclide release from the EBS (NRC 1999b, p. 30).

    - Maps to integrated subissues: ENG1, ENG2, ENG3, and ENG4 (see descriptions above).

Each of the six Container Life and Source Term subissues is addressed in the form of principal components, as is illustrated Figure 4-2. Subissues of the Container Life and Source Term IRSR provide input to the Engineered Barriers and Direct Release and Transport subsystem components integrated subissues (see Figure 4-1 in Section 4.2.4). Integrated subissues, in general, represent the integrated processes, features, and events that could impact system performance that should be abstracted into the TSPA (NRC 2000, p. 30). As shown in Figure 4-2, disruptive events analyses contribute to addressing the subissues effects of instability and initial defects on mechanical failure and container lifetime, and effects of alternate EBS designs on container lifetime and radionuclide release. There are seven general acceptance criteria that apply to all subissues that are listed and discussed at the end of the discussion of the Container Life and Source Term IRSR. Six of the criteria are met by all disruptive events analyses and the calculation.

The discussions of Subissue 1, Effects of Corrosion Processes on Container Lifetime, and Subissue 2, Effects of Instability and Initial Defects on Mechanical Failure and Container Lifetime, both indicate that disruptive events analyses do not contribute directly to Subissue 1. Disruptive events are explicitly discussed under Subissue 2. The effect of disruptive events on corrosion is indirect through adverse effects on the mechanical properties of the WP that potentially could cause acceleration of corrosion by damage to the package wall.

The discussion of Subissue 2 states, "The component of this subissue related to the coupling of disruptive events and container material properties will be covered in future revisions of this IRSR" (NRC 1999b, p. 22). Therefore, the Disruptive Events PMR provides no discussion of how the disruptive events analyses address this subissue. The Container Life and Source Term IRSR does state that "Disruptive events, such as seismic activity, volcanism, and faulting may promote premature failure of the containers through different processes" giving the example of seismic events causing mechanical stresses that may cause fracture of a container (NRC 1999b, p. 22). The Container Life and Source Term IRSR (NRC 1999b, p. 10) also refers to discussions of the effect of disruptive events on the mechanical integrity of WPs in three other IRSRs: Igneous Activity (Reamer 1999), Structural Deformation and Seismicity (NRC 1999a), and Repository Design and Thermal-Mechanical Effects (NRC 1999c). How disruptive events analyses address WP integrity issues is discussed for each of these IRSRs in Sections 4.3, 4.4, and 4.6, respectively, of this PMR.

Subissue 3 (rate of SNF radionuclide release from EBS) has eight components. The primary focus of this subissue is on the radionuclides and factors that affect their release, including compromise of protective barriers such as cladding. Disruptive events analyses for the Disruptive Events PMR do not contribute directly to analyses of cladding failure but do support the analysis indirectly by providing information about the development of ground motion hazard curves used in cladding analysis. The discussion in the disruptive events AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c) provides summary level background information on seismicity in the Yucca Mountain region that supports understanding of the derivation of ground motion hazard curves. Analysis of the effects of ground motion on cladding breakage was performed under the Waste Form PMR group of analyses (CRWMS M&O 1999f). Because disruptive events analyses support this subissue indirectly, no comparison of disruptive events analyses to acceptance criteria is made for this subissue.

Subissue 4 (rate of HLW glass radionuclide release from EBS) and Subissue 5 (effects of in-package criticality on WP and EBS performance) are not addressed by disruptive events analyses. Chapter 1 of the Disruptive Events PMR mentions that criticality was shown by the TSPA-VA analysis to be of low consequence. Criticality will be treated in a future version of the YMP FEPs database.

Subissue 6 (effects of alternate EBS designs on container lifetime and radionuclide release) is addressed by disruptive events analyses. Ceramic coatings were not in any of the design alternatives considered during the time period in which the disruptive events analyses were performed, but backfill and drip shields were. There are eight acceptance criteria for this subissue. Two apply to ceramic coatings specifically; two apply to testing programs and use of test results from sources outside the Yucca Mountain testing program; and one each applies to the container wall thickness and water composition, leaving only two that are addressed by disruptive events analyses. Comparison of those two acceptance criteria to disruptive events analyses is shown in Table 4-11.

Table 4-11. IRSR KTI Container Life and Source Term Subissue 6, Effects of Alternate EBS Designs on Container Lifetime and Radionuclide Release, Acceptance Criteria Addressed by Disruptive Events Analyses

Acceptance Criterion	Disruptive Events Analysis/Calculation
1) DOE has identified and considered the effects of backfill, and the timing of its emplacement, on the thermal loading of the repository, WP lifetime (including container corrosion and mechanical failure), and the release of radionuclides from the EBS.	[1]*Dike Propagation Near Drifts*; [2]*Effects of Fault Displacement on Emplacement Drifts*; [3]*Igneous Consequence Modeling for TSPA-SR*; [4]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada;* [5]*Features, Events, and Processes: Disruptive Events*
4) DOE has identified and considered the effects of drip shields (with backfill) on WP lifetime, including extension of the humid-air corrosion regime, environmental effects, breakdown of drip shields and resulting mechanical impacts on WP, the potential for crevice corrosion at the junction between the WP and the drip shield, and the potential for condensate formation and dripping on the underside of the shield.	[1]*Dike Propagation Near Drifts*; [2]*Effects of Fault Displacement on Emplacement Drifts*; [3]*Igneous Consequence Modeling for TSPA-SR*; [4]*Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada;* [5]*Features, Events, and Processes: Disruptive Events*

Sources: NRC 1999b, pp. 30 to 31;[1]CRWMS M&O 2000e; [2]CRWMS M&O 2000g; [3]CRWMS M&O 2000l; [4]CRWMS M&O 2000c; [5]CRWMS M&O 2000h

Disruptive events analyses were begun using a design having no enhancements (DOE 1998b, Volume 2, Section 5, p. 8-14). For this design, impacts on WPs from rockfall initiated by ground motion events were analyzed by the EBS group and modifications were made to the TSPA Waste Package Degradation Model (WAPDEG) to support disruptive events modeling for TSPA (CRWMS M&O 2000f). The rockfall analysis used ground motion hazard curves from the PSHA summarized in the AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c). The rockfall analysis and TSPA code modifications were retained after the design with backfill came in.

When the design change was made to include backfill and drip shields, the disruptive events analyses were completed using that design: EDA II, Design B (CRWMS M&O 1999a). These enhancements negated the effects of rockfall and restricted the length of drift that would be affected by magma flow during an igneous dike intrusion event. The AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) addresses the length of drift that would be affected by an igneous dike intrusion into the repository and determined that the presence of backfill would limit the length magma could flow down a drift. The AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) includes the assumptions that (1) all WPs within a conduit that formed during a volcanic eruption release event or that were contacted by magma during an igneous intrusion groundwater release event were completely compromised and (2) all of their contents were available for transport. These assumptions treat the effects of all design alternatives the same and provide flexibility for the TSPA-SR calculation.

Subsequent modification to the preferred design that removed backfill, retained drip shields, and realigned the drifts (shifting their alignment with regard to faults and joints) necessitated further analyses, and those are covered by changes to the AMRs and calculation made through the ICN process described in AP 3.10Q. Removal of backfill has a major impact on the analysis of how far magma could flow down a drift in the AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e). The removal of backfill has a downstream effect on the AMR *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k) and on the resulting input into the TSPA-SR that is prepared by AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l). The disruptive events calculation *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k) performs a calculation based on the geometry of the repository, drifts, and WP placement that uses inputs from several AMRs and makes no adjustments to the calculation procedure based on design. For this calculation, the results may be recalculated, but the calculation method would not need reworking because of a design change. For the AMR *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g), reassessment of the problem being analyzed using the design without backfill shows that fault displacement effects on drip shields, with or without backfill, given that stresses are parallel to the long axis of the drifts, would be the same.

The IRSR states that the NRC staff will evaluate whether DOE's technical bases reflect important physical phenomena and processes, consistent assumptions and definitions, consideration of alternative models, bounding approaches, adequate abstraction of process models, appropriate expert judgments, and QA documentation. These subjects are covered in nine general acceptance criteria that apply to all Container Life and Source Term IRSR subissues and are listed below (NRC 1999b, p. 19). Disruptive events analyses and the calculation support addressing subissues 2 and 6. Because there are no specific acceptance criteria for subissue 2 (as of Revision 2 of the IRSR), it is assumed that the general acceptance criteria and the manner in which disruptive events work supports addressing them will be the same for both subissues. The general acceptance criteria are listed below (NRC 1999b, pp. 19 to 20), and reference is made comparing them to the programmatic and technical acceptance criteria from the Total System Performance Assessment and Integration IRSR (NRC 2000) that apply to all IRSRs:

1. The collection and documentation of data, as well as development and documentation of analyses, methods, models, and codes, were accomplished under approved QA and control procedures and standards. (This criterion is similar to Programmatic Criterion P1 described in Section 4.7.1.)

2. Expert elicitations, when used, were conducted and documented in accordance with the guidance provided in the Branch Technical Position on Expert Elicitation (Kotra et al. 1996) or other acceptable approaches. (This criterion is similar to Programmatic Criterion P2 described in Section 4.7.1.)

3. Sufficient data (field, laboratory, and natural analog) are available to adequately define relevant parameters for the models used to evaluate performance aspects of the subissues. (This criterion is similar to Technical Criterion T1 described in Section 4.7.1.)

4. Sensitivity and uncertainty analyses (including consideration of alternative conceptual models) were used to determine whether additional data would be needed to better define ranges of input parameters.

5. Parameter values, assumed ranges, test data, probability distributions, and bounding assumptions used in the models are technically defensible and can reasonably account for known uncertainties. (This criterion is similar to Technical Criterion T2 described in Section 4.7.1.)

6. Mathematical model limitations and uncertainties in modeling were defined and documented.

7. Primary and alternative modeling approaches consistent with available data and current scientific understanding were investigated and their results and limitations considered in evaluating the subissue. (This criterion is similar to Technical Criterion T3 described in Section 4.7.1.)

8. Model outputs were validated through comparisons with outputs of detailed process models, empirical observations, or both. (This criterion is similar to Technical Criterion T4 described in Section 4.7.1.)

9. The structure and organization of process and abstracted models were found to adequately incorporate important design features, physical phenomena, and coupled processes. (This criterion is similar to Technical Criterion T5 described in Section 4.7.1.)

All disruptive events analyses and the calculation address all the acceptance criteria for subissues 2 and 6. Since seven of the nine general acceptance criteria for this IRSR map to others already described in Section 4.7.1 of this PMR, only criteria 4, 6, and 8 (with supporting information from discussion of criterion 5) will be discussed here. Disruptive events analyses support sensitivity studies in the TSPA-SR, acceptance criterion 4, by providing discussion of alternative conceptual models for the processes analyzed and by providing suggested data and parameter ranges used to model the processes. Technical defensibility of the topics listed in acceptance criterion 5 is accomplished in the disruptive events AMRs and calculation by listing assumptions in Chapter 3 and by describing sources of data in Chapter 4 for the AMRs and Chapter 5 for the calculation. Technical defensibility is also supported by description of the analysis and conclusions in Chapters 6 and 7 of the AMRs and Chapters 5 and 6 of the calculation. Incorporation of uncertainty is accomplished by the use of ranges and distributions of data in analyses and calculations and by the consideration of alternative conceptual models. Acceptance criterion 6 was met in the same manner as described for acceptance criterion 5 with the addition of support from the analyses described in Chapter 6 of the AMRs and Chapters 5 and 6 of the calculation. Validation of model outputs is an activity performed by TSPA-SR analysis; however, all disruptive events AMRs provide documentation of analyses that may be used when comparison with process models and empirical observations is required. In this manner disruptive events analyses provide support for meeting acceptance criterion 8.

4.6 NRC KTI REPOSITORY DESIGN AND THERMAL-MECHANICAL EFFECTS

As stated in the Repository Design and Thermal-Mechanical Effects IRSR: "The primary focus of the Repository Design and Thermal-Mechanical Effects (RDTME) KTI is the review of design, construction, and operation of the geologic repository operations area (GROA) with regard to the preclosure and postclosure performance objectives, taking into consideration the long-term thermal-mechanical (TM) processes" (NRC 1999c, Section 2.1). Disruptive events analyses provide limited support addressing subissues 2 and 3 in the subissues list below, however, primary support for addressing the KTI Repository Design and Thermal-Mechanical Effects is through work performed under WP and EBS PMRs. The KTI Issue Repository Design and Thermal-Mechanical Effects is divided into four subissues (NRC 1999c, pp. 3 to 4). Each subissue may be addressed in terms of its principal components (NRC 1999c, p. 4) which are listed for the two subissues that are given limited support by disruptive events analyses:

1. Subissue 1: Design Control Process–Implementation of an Effective Design Control Process Within the Overall Quality Assurance Program
2. Subissue 2: Seismic Design Methodology–Design of the GROA [geologic repository operations area] for the Effects of Seismic Events and Direct Fault Disruption [including implications for drift stability and key aspects of emplacement configuration (i.e., fault offset distance, retrievability, and WP damage)]

Principal components: (i) DOE's methodology to assess seismic and fault displacement hazard, (ii) DOE's seismic design methodology, and (iii) seismic and fault displacement inputs to the design and PAs. [Note: Component ii and parts of iii are dealt with through the Repository Design and Thermal-Mechanical Effects IRSR, and the remaining items are dealt with through the Structural Deformation and Seismicity IRSR.]

- Maps to integrated subissue: ENG2 Mechanical Disruption of Engineered Barriers

3. Subissue 3: Thermal-Mechanical Effects–Consideration of TM [thermal-mechanical] Effects on Underground Facility Design and Performance (including implications for drift stability, key aspects of emplacement configuration that may influence thermal loads and associated thermo-mechanical effects, retrievability, and flow into and out of emplacement drifts and fault setback distance)

   Principal components: (i) stability of the underground excavations with regard to safety during the preclosure period, waste retrievability, and potential adverse effects on emplaced wastes; (ii) effect of seismically induced rockfall with respect to WP performance; (iii) changes of emplacement drift geometries and hydrological properties surrounding emplacement drifts due to thermal-mechanical perturbation of the rock mass

   - Maps to integrated subissues: ENG1 Degradation of Engineered Barriers, ENG2 (see description above), ENG3 Quantity and Chemistry of Water Contacting the Waste Packages and Waste Forms, and UZ1 Spatial and Temporal Distribution of Flow

4. Subissue 4: Design and Long-Term Contribution of Seals to Performance–Design and Long-Term Contribution of Repository Seals in Meeting the Postclosure Performance Objectives (including implications for inflow of water and release of radionuclides to the environment).

4.6.1 Disruptive Events Analyses and Calculation That Address the KTI Subissues

Disruptive events analyses, both past and present, support addressing the Repository Design and Thermal-Mechanical Effects IRSR Subissue 2, Seismic Design Methodology (component iii) and Subissue 3, Thermal-Mechanical Effects (component ii). In the analysis of repository performance summarized in the Total System Performance Assessment and Integration IRSR (NRC 2000, Figure 3) and in Figure 4-1 of the Disruptive Events PMR, inputs from Repository Design and Thermal-Mechanical Effects subissues feed into the engineered barriers and UZ flow and transport subsystem components. Subissue 2, Seismic Design Methodology, from the Repository Design and Thermal-Mechanical Effects IRSR provides inputs to the mechanical disruption of engineered barriers integrated subissue of the engineered barriers subsystem component (Figure 4-1). How this subissue is addressed by disruptive events analyses is discussed in Section 4.4 of this Disruptive Events PMR.

Discussion of Subissue 2 (component iii) (NRC 1999c, p. 4) is influenced by what the NRC indicates as "DOE and staff agreed that the issue of seismicity and fault displacement is an appropriate one to be dealt with through the TR [Topical Report] process" (NRC 1999c, p. 23). Discussion of NRC response to the Topical Reports comprises the discussion of the subissue. Past and present disruptive events analyses support this, and the other aspects of the subissue, by being part of the process of developing a seismic design that serves both preclosure and postclosure needs through iterations involving a design concept and analyses of the potential effects of that design on TSPA outcome. Feedback from analyses, including previous disruptive events analyses, influenced subsequent Topical Report revisions because they showed whether the proposed design met performance standards for containment and, in turn, analyses use results from Topical Reports. The current disruptive events analyses for TSPA-SR came after the existing revisions of Topical Reports 1 and 2, but will influence Topical Report 3, which is to be developed after TSPA-SR. For clarity, the subjects of the Topical Reports are discussed below.

Two Topical Reports have been produced by the DOE. The first, *Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain* (YMP 1997a) described a five-step process for assessing the vibratory ground motion and fault displacement hazards at the site. Implementation of the method described in the Topical Report led to the expert elicitation that is summarized in the disruptive events AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c). The second Topical Report, *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain* (YMP 1997b), described the method that DOE proposed to use to develop the preclosure seismic design for the repository. The third Topical Report, *Preclosure Seismic Design Basis for a Geologic Repository at Yucca Mountain* (development plan, CRWMS M&O 1999h), will discuss the vibratory ground motion and fault displacement hazards at the site, describe the seismic design inputs, and discuss the potential postclosure effects of vibratory ground motion and fault displacement. This Topical Report will not be finished until after the SR.

Subissue 3 of the Repository Design and Thermal-Mechanical Effects IRSR, Thermal-mechanical Effects, focuses on the effects that thermal-mechanical stresses are expected to have on existing in situ lithologic stresses throughout the postclosure period. The issue examines how thermal-mechanical effects on the host rock of the repository will affect drift stability in the presence of seismically induced ground motion with the principal component (iii) partially addressed by disruptive events analyses focusing on the effects of seismically induced rockfall. The disruptive events AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c) and this Disruptive Events PMR support traceability and transparency of rockfall analyses (CRWMS M&O 2000f) performed under the EBS PMR by describing the framework for seismicity and providing a road map into the expert elicitation that produced the ground motion hazard curves.

4.7 NRC KTI ACCEPTANCE CRITERIA ADDRESSED BY DISRUPTIVE EVENTS ANALYSES AND CALCULATION

This section presents a tabulated summary of the KTIs, subissues, and acceptance criteria addressed by disruptive events analyses and the calculation. Only those acceptance criteria that are addressed by disruptive events analyses are listed. For a comprehensive list of the acceptance criteria see the NRC IRSRs.

4.7.1 Acceptance Criteria Introduced in the Total System Performance Assessment and Integration IRSR That Are Applicable to This and Other IRSRs

The Total System Performance Assessment and Integration IRSR presents programmatic and technical acceptance criteria that apply to all subissues in the IRSR. These same acceptance criteria appear, with slightly altered wording, in other IRSRs addressed by disruptive events analyses. For instance, Programmatic Acceptance Criterion P1 (see below) from this IRSR is the same as Probability Acceptance Criterion 9 in the Igneous Activity IRSR (Reamer 1999), Generic Acceptance Criterion 6 in the Structural Deformation and Seismicity IRSR (NRC 1999a, p. 20), and General Acceptance Criterion 1 in the Container Life and Source Term IRSR (NRC 1999b, p. 19). The manner in which these seven criteria are addressed by disruptive events analyses and the calculation is explained in this section in support of the more abbreviated explanation in Table 4-12. The programmatic and technical acceptance criteria that apply to several IRSRs are as follows.

Programmatic acceptance Criterion P1 states: “The collection, documentation, and development of data, models, and/or computer codes have been performed under acceptable QA procedures, or if the data, models, and/or computer codes were not subjected to an acceptable QA procedure, they have been appropriately qualified” (NRC 2000, p. 8). Each disruptive events AMR and the calculation describes the QA procedures under which it was developed (Chapter 2) and the qualification status of software, models, and data used for the analysis (Chapters 3 and 4 for analyses and Chapter 4 for calculation). The Document Input Reference System entries for each AMR capture information used in tracking the completion of qualification and verification activities. For this PMR, the QA framework under which it was developed is discussed in Section 1.3.

Programmatic acceptance Criterion P2 states: “Formal expert elicitations can be used to support data synthesis and model development for the DOE’s TSPA, provided that the elicitations are conducted and documented under acceptable procedures” (NRC 2000, p. 8). Two AMRs summarize the results of the two expert elicitations relevant to disruptive events analysis, the PSHA (Wong and Stepp 1998) and the PVHA (CRWMS M&O 1996). DOE met acceptance Criterion P2 at the time of the expert elicitations that are summarized in the disruptive events AMRs *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) and *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c). These two AMRs summarize how that criterion was met and highlight process model elements and data important to development of conceptual models for the respective subjects of the expert elicitations, thereby supporting transparency and traceability of important assumptions.

The five technical acceptance criteria are addressed by disruptive events analyses, but in a different way than they are addressed by process model analyses. Disruptive events analyses develop conceptual models and summarize process descriptions from expert elicitations. Data for parameter development is taken from the expert elicitations and supplemented by data from the literature that is qualified as described in the individual AMRs.

Technical Criterion T1 is data and model justification and requires that: "Sufficient data (field, laboratory, or natural analog data) are available to adequately support the conceptual models, assumptions, boundary conditions and to define all relevant parameters implemented in the TSPA..." (NRC 2000, p. 32). For all AMRs and the calculation, analog data are described and used as appropriate. The expert elicitations summarized in the framework AMRs (CRWMS M&O 2000b, 2000c) were the source of the majority of data used, and data from other sources was qualified as described in the individual AMRs. The process followed for the expert elicitations, as described in the two framework AMRs, ensured that relevant data were provided to the experts for consideration. Parameter definitions, data sources, and data reduction procedures for parameters developed for the TSPA were described in each AMR.

Technical Criterion T2 is data uncertainty and requires that: "Parameter values, assumed ranges, probability distributions and bounding assumptions used in the TSPA are technically defensible and reasonably account for uncertainties and variability" (NRC 2000, p. 32). The process followed for the expert elicitations, as described in the two framework AMRs (CRWMS M&O 2000b, 2000c), ensured that these conditions were met. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs and the calculation is described in each AMR in Chapters 4, 5 and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMR originators were required to list assumptions and to justify data values, ranges, and distributions.

Technical Criterion T3 is model uncertainty and requires that: "Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations appropriately considered in the abstractions" (NRC 2000, p. 32). AMR originators discuss alternative conceptual models and data values and ranges consistent with current scientific understanding and justify use of the conceptual models selected. In addition, alternative conceptual models and data ranges, as presented in NRC IRSRs, are discussed in this chapter (Chapter 4) of this Disruptive Events PMR.

Technical Criterion T4 is model support and requires that: "Models implemented in the TSPA provide results consistent with output of detailed process models or empirical observations (laboratory testing, natural analogs, or both)" (NRC 2000, p. 32). This criterion applies to the TSPA modeling process and also to one DE AMR that contains a model. Outputs of analyses supporting the Disruptive Events PMR may be referred to in assessing whether this criterion is met.

Technical Criterion T5 is integration and requires that: "TSPA adequately incorporates important design features, physical phenomena, and couplings and uses consistent and appropriate assumptions throughout the abstraction process" (NRC 2000, p. 32). This criterion applies to the TSPA integration process and does not apply to disruptive events analyses directly. However, the TSPA relies on disruptive events analyses having appropriately incorporated design features, physical phenomena, and couplings and having used consistent and appropriate assumptions in the analytical process. Each disruptive events AMR, or calculation discusses how these topics are handled. The coupled processes of tectonics and volcanism have been described in the igneous framework AMR (CRWMS M&O 2000b) in a manner that is consistent with that presented in the PSHA (Wong and Stepp 1998). Discussion of the consistency of igneous probability estimates with tectonic models is a requirement of Probability Criterion 5 in the IRSR for igneous activity (Reamer 1999, Section 4.1.5).

Table 4-12 summarizes the subissue acceptance criteria addressed by disruptive events analyses and the calculation. For all disruptive events AMRs, the reference sections are: data input lists, Chapter 4; assumptions, Chapter 5; analysis, Chapter 6; conclusions, Chapter 7. For the disruptive events calculation, the reference sections are: assumptions and data input sources, Chapter 3; calculation, Chapter 5; results, Chapter 6.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
KTI: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (NRC 2000)	
Subissue 1 System Description and Demonstration of Multiple Barriers	This subissue has two parts: system description which is traceability and transparency and demonstration of multiple barriers. Revision 2 of the IRSR only provides acceptance criteria for transparency and traceability, therefore there is no mapping to the second part of the subissue in this table. Discussion of this KTI and its subissues is found in Section 4.2 of this Disruptive Events PMR.
System Description: Transparency and Traceability	For this part of the subissue acceptance criteria are grouped into categories related to ensuring transparency and traceability of the TSPA calculation and its supporting documentation. All disruptive events AMRs and the calculation support meeting the acceptance criteria by providing documentation for the work underlying portions of the TSPA models, assumptions, data, and other information.
Transparency and traceability category *TSPA documentation style, structure, and organization*	Acceptance criteria here address ensuring that source documents underlying the TSPA are well structured and organized to support transparency and traceability.
Technical Acceptance Criterion 1 - Documents are complete, clear, and consistent.	All disruptive events AMRs and the calculation support addressing this criterion by being complete (containing all sections required by applicable procedures) and by having content that has had several reviews for clarity and consistency.
Technical Acceptance Criterion 2 - Information is amply cross-referenced.	All disruptive events AMRs and the calculation support addressing this criterion by clearly indicating the sources of information, particularly the flow of information between disruptive events AMRs and the calculation. The Disruptive Events PMR also supports addressing this criterion by providing a high-level framework for the AMRs and the calculation with relation to each other and other YMP documents.
Transparency and traceability category *Features, Events, and Processes Identification and Screening*	This activity is supported by the TSPA FEPs analysis procedures described in Section 2.1.4 of the Disruptive Events PMR. The FEPs AMR that addresses disruptive events follows the procedures developed for the TSPA as a whole.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Technical Acceptance Criterion 1 - The screening process by which FEPs were included or excluded from the TSPA is fully described	The AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) contains the information regarding include/exclude decisions for disruptive events FEPs.
Technical Acceptance Criterion 2 - Relationships between relevant FEPs are fully described.	The AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) contains the information regarding relationships between relevant FEPs for disruptive events FEPs.
Transparency and traceability category *Abstraction Methodology*	Meeting criteria under this category includes providing documentation that identifies the relationship of the site information and the actual repository design to the assumptions, models, and parameters used in the PA calculations.
Technical Acceptance Criterion 1 - The levels and method(s) of abstraction are described starting from assumptions defining the scope of the assessment down to assumptions concerning specific processes and the validity of given data.	The disruptive events AMRs that provide documentation of the linkage from data to assumptions and conceptual models that describe the disruptive events and processes of concern in TSPA-SR are *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c), *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i), *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b), *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a), *Dike Propagation Near Drifts* (CRWMS M&O 2000e), and *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l).
Technical Acceptance Criterion 2 - A mapping (e.g., a road map diagram, a traceability matrix, a cross-reference matrix) is provided to show what conceptual features (e.g., patterns of volcanic events) and processes are represented in the abstracted models, and by what algorithms.	All disruptive events AMRs provide this type of information; however, for application to the processes that were abstracted for TSPA-SR, the list is: *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c), *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i), *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b), *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a), *Dike Propagation Near Drifts* (CRWMS M&O 2000e), and *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l).
Transparency and traceability category *Data Use and Validity*	Data use and validity acceptance criteria focus on the transparency and traceability of data values and their pedigree and on parameter development, including disruptive events data.
Technical Acceptance Criterion 1 - The pedigree of data from laboratory tests, natural analogs, and the site is clearly identified.	All disruptive events analyses and the calculation support addressing this criterion by providing the pedigree of data including natural analog data.
Technical Acceptance Criterion 2 - Input parameter development and basis for their selection is described.	All disruptive events analyses and the calculation support addressing this criterion by providing a conceptual framework for development of parameters that links them to the disruptive geological event of importance. For TSPA-SR only igneous activity was modeled as a disruptive event, and the AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) provided support for TSPA input parameter development. This AMR received data from supporting AMRs as described in Section 3.1.5 of this Disruptive Events PMR.
Transparency and traceability category *Assessment Results*	Assessment of results acceptance criteria focus on making results transparent and traceable down through the level of individual components or subsystems of the repository, including disruptive events.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Technical Acceptance Criterion 1 - PA results (i.e., the peak expected annual dose within the compliance period) can be traced back to applicable analyses that identify the FEPs, assumptions, input parameters, and models in the PA.	All disruptive events analyses and the calculation support addressing this by providing the underlying analyses documented in a clear manner. In particular, the disruptive events AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) provides information on assumptions, models, and parameters for igneous consequence modeling in the TSPA-SR, and the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) provides FEPs analysis disruptive events.
Subissue 2 - Scenario Analysis *Identification of an initial set of processes and events* Technical Acceptance Criterion 1 - DOE has identified a comprehensive list of processes and events that: (1) are present or might occur in the Yucca Mountain region and (2) includes those processes and events that have the potential to influence repository performance. Review Method for this acceptance criterion says DOE should include processes and events related to igneous activity, seismic shaking (high frequency low magnitude and rare large magnitude events), tectonic evolution (slip on existing faults and formation of new faults), climatic change, and criticality.	The YMP FEPs database (CRWMS M&O 2000j) contains an initial list of comprehensive FEPs that cover natural and engineered components for the setting of the potential repository. Within each PMR, individual FEPs AMRs address portions of this list for completeness and evaluate FEPs. For disruptive events this criterion is addressed by the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h).
Classification of Processes and Events Technical Acceptance Criterion 1 - DOE has provided adequate documentation identifying how its initial list of processes and events has been grouped into categories.	A preliminary grouping of FEPs into primary and secondary categories was performed within the YMP FEPs database (CRWMS M&O 2000j). The entries in the YMP FEPs database were grouped into areas focused on those represented by the nine PMRs for TSPA-SR, and within the PMR group of analyses there was a FEPs AMR for each PMR. For disruptive events the AMR *Features, Events, and Processes: Disruptive Events* documents these groupings (CRWMS M&O 2000h).
Classification of Processes and Events Technical Acceptance Criterion 2 - Categorization of processes and events is compatible with the use of categories during the screening of processes and events.	Screening of categories of events and processes (i.e., of primary and secondary FEPs) is addressed in FEPs AMRs for each PMR. For disruptive events this criterion is addressed in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h).
Screening of Processes and Events Technical Acceptance Criterion 1 - Categories of processes and events that are not credible for the Yucca Mountain repository because of waste characteristics, repository design, or site characteristics are identified and sufficient justification is provided for DOE's conclusions.	Screening of FEPs, including the identification of any processes and events that are not credible for the potential repository is addressed in FEPs AMRs for each PMR. For disruptive events this criterion is addressed in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h).

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Screening of Processes and Events Technical Acceptance Criterion 2 - The probability assigned to each category of processes and events not screened based on criterion T1 or T2 is consistent with site information, well documented, and appropriately considers uncertainty. The Review Method states that NRC staff will focus on those categories that have (1) probabilities close to the screening criteria on probability and (2) potentially significant probability-weighted consequences.	Probabilities for categories of processes and events are assigned only for those FEPs that are shown to be credible at Yucca Mountain and have a significant effect on overall performance. For potentially disruptive events, probabilities are less than one (i.e., the events are not certain to occur during the 10,000-year performance period). Disruptive event probabilities are described in the AMRs *Characterize Framework for Seismicity* and *Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c), *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b), and *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h).
Screening of Processes and Events Technical Acceptance Criterion 3 - DOE has demonstrated that processes and events screened from the PA on the basis of their probability of occurrence, have a probability of less than one chance in 10,000 of occurring over 10,000 years.	Screening of categories of events and processes (i.e., of primary and secondary FEPs) is addressed in FEPs AMRs for each PMR. For disruptive events this criterion is addressed in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h). Probability values used in TSPA-SR calculations are derived from expert elicitation in the areas of igneous activity (PVHA) (CRWMS M&O 1996) and seismicity (PSHA) (Wong and Stepp 1998).
Screening of Processes and Events Technical Acceptance Criterion 4 - DOE has demonstrated that categories of processes and events omitted from the PA on the basis that their omission would not significantly change the calculated expected annual dose, do not significantly change the calculated expected annual dose.	Screening of categories of events and processes (i.e., of primary and secondary FEPs) is addressed in FEPs AMRs for each PMR. For disruptive events this criterion is addressed in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h). Demonstration that categories of processes and events omitted from the PA do not affect the calculated expected annual dose lies with the TSPA calculation and its documentation and is supported by the disruptive events FEPs AMR.
Formation of Scenarios Technical Acceptance Criterion 1 - DOE has provided adequate documentation identifying: (1) whether processes and events have been addressed through consequence model abstraction or scenario analysis and (2) how the remaining categories of processes and events have been combined into scenario classes.	Documentation of how categories of events and processes have been included in the TSPA analysis is summarized for each PMR in the FEPs AMR. For disruptive events this criterion is addressed by the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h). Documentation of the construction of scenario classes for the TSPA-SR is provided in TSPA-SR documentation and is outside of the scope of the PMR.
Acceptance Criterion Screening of Scenario Classes Technical Acceptance Criterion 1 - DOE has provided adequate documentation identifying: (1) whether processes and events have been addressed through consequence model abstraction or scenario analysis and (2) how the remaining categories of processes and events have been combined into scenario classes.	Documentation of the construction of scenario classes for the TSPA-SR is provided in TSPA-SR documentation and is outside of the scope of the PMR. For disruptive events FEPs screening is addressed by the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h). Disruptive events analyses do not produce a process model that is abstracted.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Screening of Scenario Classes Technical Acceptance Criterion 2 - The probability assigned to each scenario class is consistent with site information, well documented, and appropriately considers uncertainty.	Documentation of the construction of scenario classes for the TSPA-SR is provided in TSPA-SR documentation and is outside of the scope of the PMR. Probability values used in TSPA-SR calculations are derived from expert elicitation in the areas of igneous activity (PVHA) (CRWMS M&O 1996) and seismicity (PSHA) (Wong and Stepp 1998) and are summarized in the disruptive events AMRs *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) and *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c), respectively.
Screening of Scenario Classes Technical Acceptance Criterion 3 - Scenario classes that combine categories of processes and events may be screened from the PA on the basis of their probability of occurrence, provided: (1) the probability used for screening the scenario class is defined from combinations of initiating processes and events and (2) DOE has demonstrated that they have a probability of less than one chance in 10,000 of occurring over 10,000 years.	Documentation of the construction of scenario classes for the TSPA-SR is provided in TSPA-SR documentation and is outside of the scope of the PMR. For disruptive events screening of FEPs is addressed by the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h). Probability values used in TSPA-SR calculations are derived from expert elicitation in the areas of igneous activity (PVHA) (CRWMS M&O 1996) and seismicity (PSHA) (Wong and Stepp 1998) and are summarized in the disruptive events AMRs *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) *and Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c), respectively.
Screening of Scenario Classes Technical Acceptance Criterion 4 - Scenario classes may be omitted from the PA on the basis that their omission would not significantly change the calculated expected annual dose, provided DOE has demonstrated that excluded categories of processes and events would not significantly change the calculated expected annual dose.	Documentation of the construction of scenario classes for the TSPA-SR is provided in TSPA-SR documentation and is outside of the scope of the PMR. For disruptive events screening of FEPs is addressed by the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h). Demonstration that scenario classes omitted from the PA do not affect the calculated expected annual dose lies with the TSPA calculation and its documentation and is supported by the disruptive events FEPs AMR.
Subissue 3 - Model abstraction Subsystem Component Engineered Barriers Integrated subissue *Mechanical Disruption of Engineered Barriers*	Dike intrusion disruption on the WP part of the engineered barrier was treated in the igneous intrusion groundwater transport analysis in the AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l). The AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) contained several FEPs screening arguments related to mechanical effects of WPs that could result from ground motion or fault displacement.
Technical Acceptance Criterion 1 - Sufficient data (field, laboratory and/or natural analog data) are available to adequately define relevant parameters and conceptual model models necessary for developing mechanical disruption of the engineered barriers abstraction into the TSPA. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the TSPA.	In all disruptive events AMRs and the calculation that address the subissue (CRWMS M&O 2000a, 2000b, 2000c, 2000e, 2000g, 2000h, 2000i, 2000k, 2000l), analog data are described and used as appropriate. The expert elicitations summarized in the framework AMRs (CRWMS M&O 2000b, 2000c) were the source of the majority of data used and data from other sources was qualified as described in the individual AMRs. The process followed for the expert elicitations, as described in the two framework AMRs, ensured that relevant data were provided to the experts for consideration.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Technical Acceptance Criterion 2 - Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the mechanical disruption of engineered barriers abstraction, such as probabilistic seismic hazard curves, probability of dike intrusion, and the probability and amount of fault displacement, are technically defensible and reasonably account for uncertainties and variabilities.	The process followed for the expert elicitations, as described in the two framework AMRs (CRWMS M&O 2000b, 2000c), ensured that these conditions were met for all technical subjects contained in the criterion. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs and the calculation is described in each AMR in Chapters 4, 5, and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMR originators were required to list assumptions and to justify data values, ranges, and distributions.
Technical Acceptance Criterion 3 - Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations appropriately factored into the mechanical disruption of engineered barriers abstraction.	All disruptive events AMR originators in Chapter 6 of the AMRs were required to discuss alternative conceptual models and data values and ranges consistent with current scientific understanding and to justify use of the conceptual models selected. In addition, significant alternative conceptual models as presented in NRC IRSRs are discussed in this chapter (4) of this Disruptive Events PMR.
Subsystem Component UZ Flow and Transport Integrated subissue *Spatial and Temporal Distribution of Flow*	For this subsystem integrated subissue, the effects of faulting as a disruptive event were analyzed in the AMR *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i), which examined the effects of fault movement on fractures that, in turn, could increase flow rates, change perched water distribution, or change the relative flux between fracture and matrix.
Technical Acceptance Criterion 1 - Sufficient data (field, laboratory and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the spatial and temporal distribution of flow abstraction in TSPA. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the TSPA.	In all disruptive events AMRs and the calculation that address the subissue (CRWMS M&O 2000a, 2000b, 2000c, 2000e, 2000g, 2000h, 2000i, 2000k, 2000l), analog data are described and used as appropriate. The expert elicitations summarized in the framework AMRs (CRWMS M&O 2000b, 2000c) were the source of the majority of data used and data from other sources was qualified as described in the individual AMRs. The process followed for the expert elicitations, as described in the two framework AMRs, ensured that relevant data were provided to the experts for consideration.
Technical Acceptance Criterion 2 - Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the spatial and temporal distribution of flow abstraction [such as the effects of climate change on infiltration, near surface influences (e.g., evapotranspiration and runoff) on infiltration, structural controls on the spatial distribution of deep percolation, and thermal reflux owing to repository heat load] are technically defensible and reasonably account for uncertainties and variabilities.	The process followed for the expert elicitations, as described in the two framework AMRs (CRWMS M&O 2000b, 2000c), ensured that these conditions were met for all the technical subjects contained in the criterion. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs and the calculation is described in each AMR in Chapters 4, 5, and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMR originators were required to list assumptions and to justify data values, ranges, and distributions.
Technical Acceptance Criterion 3 - Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations appropriately factored into the spatial and temporal distribution of flow abstraction.	All disruptive events AMR originators in Chapter 6 of the AMRs were required to discuss alternative conceptual models and data values and ranges consistent with current scientific understanding and to justify use of the conceptual models selected. In addition, significant alternative conceptual models as presented in NRC IRSRs are discussed in this chapter (4) of this Disruptive Events PMR.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Subsystem Component UZ Flow and Transport Integrated subissue *Flow Paths in the UZ*	For this subsystem integrated subissue, the effects of faulting as a disruptive event are analyzed in the AMR *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i), which examines the effects of fault movement on fractures that, in turn, could increase flow rates, change perched water distribution, or change the relative flux between fracture and matrix.
Technical Acceptance Criterion 1 - Sufficient data (field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the flow paths in the UZ in the abstraction in TSPA. Where adequate data cannot be readily obtained, other information sources such as expert elicitation or bounding values have been appropriately incorporated into the TSPA.	In all disruptive events AMRs and the calculation that address the subissue (CRWMS M&O 2000a, 2000b, 2000c, 2000e, 2000g, 2000h, 2000i, 2000k, 2000l), analog data are described and used as appropriate. The expert elicitations summarized in the framework AMRs (CRWMS M&O 2000b, 2000c) are the source of the majority of data used, and data from other sources is qualified as described in the individual AMRs. The process followed for the expert elicitations, as described in the two framework AMRs, ensured that relevant data were provided to the experts for consideration.
Technical Acceptance Criterion 2 - Parameter values, assumed ranges, probability distributions, and/or bounding assumptions used in the flow paths in the UZ in the abstraction, such as hydrologic properties, stratigraphy, and infiltration rate, are technically defensible and reasonably account for uncertainties and variabilities.	The process followed for the expert elicitations, as described in the two framework AMRs (CRWMS M&O 2000b, 2000c), ensured that these conditions were met for all technical subjects contained in the criterion. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs and the calculation is described in each AMR in Chapters 4, 5, and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMR originators were required to list assumptions and to justify data values, ranges, and distributions.
Technical Acceptance Criterion 3 - Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations appropriately factored into the distribution on mass flux between fracture and matrix in the abstraction.	All disruptive events AMR originators in Chapter 6 of the AMRs discuss alternative conceptual models and data values and ranges consistent with current scientific understanding and justify use of the conceptual models selected. In addition, significant alternative conceptual models as presented in NRC IRSRs are discussed in this chapter (4) of this Disruptive Events PMR.
Subsystem Component Direct Release and Transport Integrated Subissue *Volcanic Disruption of WPs*	This subsystem integrated subissue was addressed by several AMRs and the calculation, the results of which combine to arrive at the number of WPs contacted by an extrusive and intrusive volcanic event (CRWMS M&O 2000a, 2000b, 2000k).
Technical Acceptance Criterion 1 - Sufficient data (field, laboratory, or natural analog data) are available to adequately define relevant parameters and conceptual models necessary for abstracting the volcanic disruption of WPs in TSPA. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the TSPA.	In all disruptive events AMRs and the calculation that address the subissue (CRWMS M&O 2000a, 2000b, 2000c, 2000e, 2000g, 2000h, 2000i, 2000k, 2000l), analog data are described and used as appropriate. The expert elicitations summarized in the framework AMRs (CRWMS M&O 2000b, 2000c) were the source of the majority of data used, and data from other sources is qualified as described in the individual AMRs. The process followed for the expert elicitations, as described in the two framework AMRs, ensured that relevant data were provided to the experts for consideration.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Technical Acceptance Criterion 2 - Parameter values, assumed ranges, probability distributions, and bounding assumptions used in abstracting the volcanic disruption of WPs are technically defensible and reasonably account for uncertainties and variability. The technical basis for the parameter values used in the PA needs to be provided.	The process followed for the expert elicitations, as described in the two framework AMRs (CRWMS M&O 2000b, 2000c), ensured that these conditions were met for all technical subjects contained in the criterion. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs and the calculation is described in each AMR in Chapters 4, 5, and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMR originators were required to list assumptions and to justify data values, ranges, and distributions.
Technical Acceptance Criterion 3 - Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations appropriately factored into the volcanic disruption of WPs abstraction.	All disruptive events AMR originators in Chapter 6 of the AMRs discuss alternative conceptual models and data values and ranges consistent with current scientific understanding and justify use of the conceptual models selected. In addition, significant alternative conceptual models as presented in NRC IRSRs are discussed in this chapter (4) of this Disruptive Events PMR.
Subsystem Component Direct Release and Transport Integrated Subissue *Abstraction Airborne Transport of Radionuclides*	For this subsystem integrated subissue airborne transport is modeled by the code ASHPLUME in TSPA-SR, and parameters are developed by the AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l).
Technical Acceptance Criterion 1 - Sufficient data (field, laboratory, and/or natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the airborne transport of radionuclides abstraction in TSPA. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the TSPA.	In all disruptive events AMRs and the calculation that address the subissue (CRWMS M&O 2000a, 2000b, 2000c, 2000e, 2000g, 2000h, 2000i, 2000k, 2000l), analog data are described and used as appropriate. The expert elicitations summarized in the framework AMRs (CRWMS M&O 2000b, 2000c) are the source of the majority of data used, and data from other sources is qualified as described in the individual AMRs. The process followed for the expert elicitations, as described in the two framework AMRs, ensured that relevant data were provided to the experts for consideration.
Technical Acceptance Criterion 2 - Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the airborne transport of radionuclides abstraction, such as the magnitude of eruption and deposition velocity, are technically defensible and reasonably account for uncertainties and variability.	The basis for selection of parameter values, such as magnitude of eruption, that are inputs to the igneous consequences modeling are described in AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a). Deposition velocities used are described in the AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l). Disruptive events AMRs support technical defensibility and reasonably account for uncertainties and variabilities for parameter values, assumed ranges, and/or bounding assumptions.
Technical Acceptance Criterion 3 - Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations appropriately factored into the airborne transport of radionuclides abstraction.	Consideration given to alternative modeling approaches is described in the AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l).
Subissue 4 - Demonstration of the Overall Performance Objective	PMR approach to overall performance is the result of the TSPA analysis itself and cannot be addressed by individual AMRs. All of the Disruptive Events AMRs address some aspects of this subissue, given the stated caveat (CRWMS M&O 2000a, 2000b, 2000c, 2000e, 2000g, 2000h, 2000j, 2000k, and 2000l).

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
KTI: IGNEOUS ACTIVITY (Reamer 1999)	
Subissue 1 - Probability Probability Acceptance Criterion 1 - The estimates are based on past patterns of igneous activity in the Yucca Mountain region.	As discussed in the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b), conceptual models used in the PVHA are consistent with past patterns of igneous activity and incorporate a range of temporal and spatial models based on the timing and distribution of past eruptive centers. The AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) also discusses past patterns of igneous activity in the Yucca Mountain region. Discussion of this KTI and its subissues is found in Section 4.3 of this Disruptive Events PMR.
Probability Acceptance Criterion 2 - The definitions of igneous events are used consistently. Intrusive and extrusive events should be distinguished and their probabilities estimated separately.	The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) discusses the definitions of igneous events used in the PVHA (CRWMS M&O 1996) and the implications of those definitions for probability calculations. The AMR also discusses event definitions used for TSPA-SR, and these definitions are used consistently. Intrusive and extrusive events are distinguished, and their probabilities are estimated separately for TSPA-SR.
Probability Acceptance Criterion 3 - The models are consistent with observed patterns of volcanic vents and related igneous features in the Yucca Mountain region.	The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) provides a detailed explanation of conceptual models of volcanism and relates them to the formulation of probability models. Models used are consistent with observed patterns of volcanic vents and related igneous features in the Yucca Mountain region.
Probability Acceptance Criterion 4 - Parameters used in probabilistic volcanic hazard assessments, related to recurrence rate of igneous activity in the Yucca Mountain region, spatial variation in frequency of igneous events, and area affected by igneous events are technically justified and documented by DOE.	As noted in the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b), the technical basis and documentation of the alternative models and parameter values are described in the PVHA and documented in the PVHA (CRWMS M&O 1996). Based on the PVHA and summary statements in the AMR (CRWMS M&O 2000b), parameters related to recurrence rate of igneous activity in the Yucca Mountain region, spatial variation in frequency of igneous events, and area affected by igneous events are technically justified and documented by DOE. The igneous framework AMR also discusses the potential impact of new data (Wernicke et al. 1998; Earthfield Technology 1995; Magsino et al. 1998) on estimates of recurrence rates and frequency of volcanic events.
Probability Acceptance Criterion 5 - The models are consistent with tectonic models proposed by NRC and DOE for the Yucca Mountain region.	The PVHA experts (CRWMS M&O 1996) used a variety of spatial and temporal models that are consistent with the tectonic models for the Yucca Mountain region. The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) presented a conceptual framework for the probability calculations based on PVHA outputs and subsequent studies.
Probability Acceptance Criterion 6 - The probability values used by DOE in PAs reflect the uncertainty in DOE's probabilistic volcanic hazard estimates.	Use of the expert elicitation process for the PVHA ensured that uncertainty was reflected in the resulting probabilistic hazard curves (CRWMS M&O 1996). Data from the PVHA form the basis for DOE's volcanism PA calculations. The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) developed probability distributions related to dike properties that reflected uncertainty in the data.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Probability Acceptance Criterion 7 - The values used (single values, distributions, or bounds on probabilities) are technically justified and account for uncertainties in probability estimates.	All of the volcanism AMRs, *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b), *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a), *Dike Propagation Near Drifts* (CRWMS M&O 2000e), *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) and *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l), and the calculation *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k) contain justification for the values used in analyses and the calculation. All of the AMRs and the calculation rely on probability estimates from the PVHA (CRWMS M&O 1996).
Probability Acceptance Criterion 8 - If used, expert elicitations were conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (Kotra et al. 1996), or other acceptable approaches.	The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) summarizes the PVHA (CRWMS M&O 1996) process, including documenting that the expert elicitation was conducted following Kotra et al. (1996).
Probability Acceptance Criterion 9 - The collection, documentation, and development of data and models have been performed under acceptable QA procedures, or if data was not collected under an established QA program, it has been qualified under appropriate QA procedures.	All of the disruptive events AMRs and the calculation (CRWMS M&O 2000a, 2000b, 2000c, 2000e, 2000g, 2000h, 2000i, 2000k, 2000l) describe the QA procedures under which they were developed (Chapter 2) and the qualification status of software, models, and data used for the analysis (Chapters 3 and 4 for analyses and Chapter 4 for calculation). The YMP Document Input Reference System entries for each AMR captures information used in tracking the completion of qualification and verification activities.
Subissue 2 - Consequences Consequences Acceptance Criterion 1 - The models are consistent with the geologic record of basaltic igneous activity within the Yucca Mountain region.	The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) provides a detailed explanation of conceptual models used, how probability models were formulated by the PVHA (CRWMS M&O 1996), and the history and characteristics of basaltic igneous activity in the Yucca Mountain region. The AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) provides data for conceptual model and parameter development that is consistent with the geologic record. The AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) collects data from the other disruptive events volcanism AMRs and develops a conceptual model and parameters for use by TSPA-SR that are consistent with the geologic record.
Consequences Acceptance Criterion 2 - The models are verified against igneous processes observed at active or recently active analog igneous systems and reflect the fundamental details of ash-plume dynamics.	The AMRs *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) and *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) discuss analog data used to develop conceptual models and parameters. The eruptive processes AMR also contributes to parameter value development for modeling ash-plume dynamics, as does the AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l).

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Consequences Acceptance Criterion 3 - The models adequately account for changes in magma ascent characteristics and magma-rock interactions brought about by repository construction.	The AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) provides a discussion of magma characteristics as it ascends including conduit properties and fragmentation behavior. Analysis of potential magma-rock interactions related to repository construction is described in the AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e). Repository orientation is an important factor in dike or conduit interaction with drifts, and the AMR *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k) relates the design to the number of packages involved in dike-conduit interaction. The AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) brings together the results of the other AMRs to summarize the effects of magma ascent characteristics and interaction with the repository for parameter development.
Consequences Acceptance Criterion 4 - The models account for the interactions of basaltic magma with engineered barriers and waste forms.	The AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) provides magma parameters, and the AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) uses those parameters and develops conceptualizations of potential interactions between magma, particles, gases, and the engineered system. The AMR *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000k) relates the design to the number of packages involved in dike-conduit interaction with the repository. The AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) brings together the results of the other AMRs and produces parameters for modeling the interactions of magma with engineered barriers and waste forms.
Consequences Acceptance Criterion 5 - The parameters are constrained by data from Yucca Mountain region igneous features and from appropriate analog systems such that the effects of igneous activity on waste containment and isolation are not underestimated.	The discussions for Consequence Acceptance Criteria 1 through 3 describe how parameters are constrained by data from Yucca Mountain region features and analogs. The discussion for Consequence Acceptance Criterion 4 describes how data from an AMR and calculation outside of the disruptive events group of analyses were used to support conceptualization of waste containment in a magmatic environment. Use of the expert elicitation process supports ensuring that effects of igneous activity on waste containment and isolation are not under-estimated.
Consequence Acceptance Criterion 6 - If used, expert elicitations were conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (Kotra et al. 1996) or other acceptable approaches.	To date there has been no DOE expert elicitation in the area of igneous consequences.
Consequences Acceptance Criterion 7 - The collection, documentation, and development of data and models have been performed under acceptable QA procedures or, if data was not collected under an established QA program, it has been qualified under appropriate QA procedures.	Each disruptive events AMR and the calculation describe the QA procedures under which it was developed (Chapter 2) and the qualification status of software, models, and data used for the analysis (Chapters 3 and 4 for analyses and Chapter 4 for calculation). The Document Input Reference System entries for each AMR capture information used in tracking the completion of qualification and verification activities. For this PMR the QA framework under which it was developed is in Section 1.3.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
KTI: STRUCTURAL DEFORMATION AND SEISMICITY (NRC 1999a)	
Subissue 1 - Faulting	There are four components of this subissue and all are addressed by disruptive events AMRs. The fault displacement hazard component is addressed by results of the PSHA (Wong and Stepp 1998), which is discussed in the AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c). This component is also addressed by the AMRs *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g), and *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i). The titles indicate the relevance to the component. Faulting causing WP failure and faulting exhuming WPs are two components, and both are addressed by the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h) in FEPs that analyze these scenarios. The component probability and consequences (risk) of faulting directly rupturing WPs is addressed in the AMRs *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c), and *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h). Discussion of this KTI and its subissues is found in Section 4.4 of this Disruptive Events PMR.
Generic Acceptance Criterion 1 - Sufficient geological and geophysical data are acquired to adequately support conceptual models of faulting, attendant assumptions, and boundary conditions and to define relevant parameters implemented in process models, TSPA calculations, or both of the direct disruption of WPs from faulting.	In all disruptive events AMRs that address the subissue (CRWMS M&O 2000c, 2000g, 2000i), the analog data are described and used as appropriate. The expert elicitation summarized in the AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c) was the source of the majority of data used, and data from other sources was qualified as described in the individual AMRs. The process followed for the expert elicitation, as described in the AMR, ensured that relevant data were provided to the experts for consideration.
Generic Acceptance Criterion 2 - Parameter values, assumed ranges, probabilistic distributions, and bounding assumptions used to develop process models, TSPA, or both of faulting are technically defensible and reasonably account for uncertainties and variabilities.	The process followed for the expert elicitation, as described in the AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c), ensured that these conditions were met for all technical subjects contained in the criterion. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs is described in each AMR in Chapters 4, 5, and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMR originators list assumptions and justify data values, ranges, and distributions.
Generic Acceptance Criterion 3 - Alternative modeling approaches for faulting are investigated, consistent with available data and current scientific understanding. Results and limitations are appropriately considered in the development of the probabilistic fault displacement hazard and included in abstractions for process, TSPA subsystem, or both models.	All disruptive events AMR originators in Chapter 6 of the AMRs discuss alternative conceptual models and data values and ranges consistent with current scientific understanding and justify use of the conceptual models selected. In addition, significant alternative conceptual models as presented in NRC IRSRs are discussed in this chapter (4) of this Disruptive Events PMR.
Generic Acceptance Criterion 4 - Results of PFDHA, TSPA subsystem, or both models are verified by comparison to output from detailed process models, empirical observations, or both.	Disruptive events analysis contained no models for faulting; therefore, no model verification is required for models covering faulting.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Generic Acceptance Criterion 5 - Incorporation of faulting models and parameters into TSPA models adequately includes important design features, physical phenomena, and coupling and relies on consistent and appropriate assumptions throughout the abstraction process.	The activity of model and parameter integration into TSPA, which is the topic of this acceptance criterion, is performed downstream of disruptive events analyses. This activity is performed by TSPA activities.
Generic Acceptance Criterion 6 - The collection, documentation, and development of data, models, and computer codes have been performed under acceptable QA procedures or, if the data, models, and computer codes were not subject to an acceptable QA procedure, they have been appropriately qualified.	Each disruptive events AMR describes the QA procedures under which it was developed (Chapter 2) and the qualification status of software, models, and data used for the analysis (Chapters 3 and 4 for analyses and Chapter 4 for calculation). The Document Input Reference System entries for each AMR captures information used in tracking the completion of qualification and verification activities. For this PMR the QA framework under which it was developed is discussed in Section 1.3.
Generic Acceptance Criterion 7 - Formal expert elicitations can be used to support data synthesis and model development for the DOE's process models, TSPA, or both provided that the elicitations were conducted and documented under acceptable procedures (e.g., Kotra et al. 1996).	The disruptive events AMR that summarizes the results of the PSHA expert elicitation for faulting (CRWMS M&O 2000c) contains a description of the conditions under which the elicitation was conducted and documented and references the PSHA documents that contain further detail (Wong and Stepp 1998).
Subissue 2 - Seismicity	This subissue has four components, all of which are addressed by disruptive events analyses. The component seismic hazard is addressed by the PSHA (Wong and Stepp 1998), which is summarized in the AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c). This component is also addressed by analyses in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h). The same two AMRs address the two components, type 1 faults and ground motion, in the same manner. The component probabilistic seismic hazard methodology and results of probabilistic seismic hazard is addressed by the PSHA (Wong and Stepp 1998), which is summarized in the AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c).
Generic Acceptance Criterion 1 - Sufficient geological and geophysical data are acquired to adequately define seismic sources, relevant earthquake and ground motion parameters, recurrence relationships, ground motion attenuation functions, and boundary conditions, and to support attendant assumptions and conceptual models implemented in the PSHA.	In the disruptive events AMR that addresses the subissue (CRWMS M&O 2000c), the use of analog data by PSHA experts (Wong and Stepp 1998) is discussed. The expert elicitation summarized in the seismic framework AMR (CRWMS M&O 2000c) was the source of the majority of data used and data from other sources was qualified as described in the individual AMRs. The process followed for the expert elicitation, as described in the framework AMR, ensured that relevant data were provided to the experts for consideration.
Generic Acceptance Criterion 2 - Parameter values, assumed ranges, probabilistic distributions, and/or bounding assumptions used to determine seismicity parameters are technically defensible and reasonably account for uncertainties and variabilities.	The process followed for the expert elicitation, as described in the framework AMR (CRWMS M&O 2000c), ensured that these conditions were met for all technical subjects contained in the criterion. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs is described in each AMR in Chapters 4, 5, and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMR originators list assumptions and justify data values, ranges, and distributions.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Generic Acceptance Criterion 3 - Alternative modeling approaches for seismicity model, such as recurrence relationships or ground motion attenuation relationships, are investigated. Results and limitations are considered in the development of the PSHA and included in the abstractions to TSPA subsystem models, consistent with available data and current scientific understanding of seismicity.	All disruptive events AMR originators in Chapter 6 of the AMRs discuss alternative conceptual models and data values and ranges consistent with current scientific understanding and justify use of the conceptual models selected. In addition, significant alternative conceptual models as presented in NRC IRSRs are discussed in this chapter (4) of this Disruptive Events PMR.
Generic Acceptance Criterion 6 - QA. This criterion and its attendant review method are applied the same way for each subissue and are not repeated here. The detailed statements of criterion 6 and the review method are described in the faulting subissue, Section 4.1.1.1.	Each disruptive events AMR describes the QA procedures under which it was developed (Chapter 2) and the qualification status of software, models, and data used for the analysis (Chapters 3 and 4 for analyses and Chapter 4 for calculation). The Document Input Reference System entries for each AMR capture information used in tracking the completion of qualification and verification activities. For this PMR the QA framework under which it was developed is discussed in Section 1.3.
Generic Acceptance Criterion 7 - Expert Elicitation. This criterion and its attendant review method are applied the same way for the faulting, seismicity and tectonic framework of the geologic setting subissues and are not repeated here. The detailed statements of criterion 7 and the review method are described in the Faulting Subissue, Section 4.1.1.1.	The disruptive events AMR that summarizes the results of the PSHA expert elicitation for faulting (CRWMS M&O 2000c) contains a description of the conditions under which the elicitation was conducted and documented and references the PSHA documents that contain further detail (Wong and Stepp 1998).
Subissue 4 - Tectonic Framework of the Geologic Setting	This subissue has four components, only one of which is addressed by disruptive events analysis. Crustal strain at Yucca Mountain is a component that is addressed by the AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) in discussing new data from Wernicke et al. (1998).
Generic Acceptance Criterion 1 - Sufficient geological and geophysical data are acquired to adequately support conceptual models of tectonics, attendant assumptions, and boundary conditions and to define relevant parameters of tectonic models implemented in process, subsystem, or PA models and calculations.	The process followed for the expert elicitation, as described in the framework AMR (CRWMS M&O 2000c), ensured that these conditions were met. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs is described in each AMR in Chapters 4, 5, and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMRs list assumptions and justify data values, ranges, and distributions.
Generic Acceptance Criterion 2 - Parameter values, assumed ranges, probabilistic distributions, and/or bounding assumptions used to develop viable tectonic models are technically defensible and reasonably account for uncertainties and variabilities.	In the disruptive events AMR that addresses the subissue (CRWMS M&O 2000c) the use of analog data by PVHA experts (Wong and Stepp 1998) is discussed. The expert elicitation summarized in the seismic framework AMR (CRWMS M&O 2000c) was the source of the majority of data used, and data from other sources was qualified as described in the individual AMRs. The process followed for the expert elicitation, as described in the framework AMR, ensured that relevant data were provided to the experts for consideration.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Generic Acceptance Criterion 3 - Alternative modeling approaches for tectonics are investigated, consistent with available data and current scientific understanding. Results and limitations of tectonic models are sufficiently considered in the development of process, subsystem and TSPA models.	The process followed for the expert elicitation, as described in the framework AMR (CRWMS M&O 2000c), ensured that these conditions were met. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs is described in each AMR in Chapters 4, 5, and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMR originators were required to list assumptions and to justify data values, ranges, and distributions.
Generic Acceptance Criterion 6 - QA. This criterion and its attendant review method are applied the same way for each subissue and are not repeated here. The detailed statements of criterion 6 and the review method are described in the Faulting Subissue, Section 4.1.1.1.	All disruptive events AMR originators in Chapter 6 of the AMRs discuss alternative conceptual models and data values and ranges consistent with current scientific understanding and justify use of the conceptual models selected. In addition, significant alternative conceptual models as presented in NRC IRSRs are discussed in this chapter (4) of this Disruptive Events PMR.
Generic Acceptance Criterion 7 - Expert Elicitation. This criterion and its attendant review method are applied the same way for the faulting, seismicity, and tectonic framework of the geologic setting subissues and is not repeated here. The detailed statements of criterion 7 and the review method are described in the Faulting Subissue, Section 4.1.1.1.	Each disruptive events AMR describes the QA procedures under which it was developed (Chapter 2) and the qualification status of software, models, and data used for the analysis (Chapters 3 and 4 for analyses and Chapter 4 for calculation). The Document Input Reference System entries for each AMR capture information used in tracking the completion of qualification and verification activities. For this PMR the QA framework under which it was developed is discussed in Section 1.3.
KTI: CONTAINER LIFE AND SOURCE TERM (NRC 1999b)	
Subissue 2 - Effects of Instability and Initial Defects on Mechanical Failure and Container Lifetime	It is stated in the IRSR that consequences of disruptive events and their effects on this subissue will be considered in detail in a subsequent revision of the IRSR. Disruptive events (seismicity, volcanism, and faulting) are specifically mentioned as being a component of this subissue; therefore, disruptive events analyses must address this subissue when the NRC defines it in the future. The manner in which disruptive events analyses address the Programmatic and Technical acceptance described in Section 4.7.1 of this Disruptive Events PMR applies to this subissue also. Discussion of this KTI and its subissues is found in Section 4.5 of this Disruptive Events PMR.
Subissue 6 - Effects of EBS Design Alternatives	There are eight specific acceptance criteria for this subissue. Disruptive events analyses address two of them (criteria 1 and 4). There are nine general acceptance criteria that apply to all subissues for this IRSR. Seven of the nine overlap with regard to subject matter with the two Programmatic and seven general acceptance criteria (Section 4.5.1 of this PMR) described in Section 4.7.1 of this Disruptive Events PMR.
Specific Acceptance Criterion 1 - DOE has identified and considered the effects of backfill, and the timing of its emplacement, on the thermal loading of the repository, WP lifetime (including container corrosion and mechanical failure), and the release of radionuclides from the EBS.	The AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) considered the effects of backfill on the distance magma could run down drifts impacting WPs. The AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) passes data from the previous AMR to TSPA-SR with the assumption that all WPs contacted by magmatic material from a dike or a conduit are damaged to the point that they do not protect the waste. The AMR *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g) considers the effects of backfill in its analysis of effects of fault displacement.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
General Acceptance Criterion 1 - The collection and documentation of data, as well as development and documentation of analyses, methods, models, and codes, were accomplished under approved QA and control procedures and standards.	Each disruptive events AMR and the calculation describe the QA procedures under which it was developed (Chapter 2) and the qualification status of software, models, and data used for the analysis (Chapters 3 and 4 for analyses and Chapter 4 for calculation). The Document Input Reference System entries for each AMR captures information used in tracking the completion of qualification and verification activities. For this PMR the QA framework under which it was developed is discussed in Section 1.3.
General Acceptance Criterion 2 - Expert elicitations, when used, were conducted and documented in accordance with the guidance provided in the Branch Technical Position on Expert Elicitation (Kotra et al. 1996) or other acceptable approaches.	The disruptive events AMR that summarizes the results of the PSHA expert elicitation for faulting (CRWMS M&O 2000c) contains a description of the conditions under which the elicitation was conducted and documented and references the PSHA document that contains further detail (Wong and Stepp 1998).
General Acceptance Criterion 3 - Sufficient data (field, laboratory, and natural analog) are available to adequately define relevant parameters for the models used to evaluate performance aspects of the subissues.	The process followed for the expert elicitation, as described in the framework AMRs (CRWMS M&O 2000b, 2000c) ensured that these conditions were met for development of hazard curves for geologic events impacting WP performance with or without backfill.
General Acceptance Criterion 4 - Sensitivity and uncertainty analyses (including consideration of alternative conceptual models) were used to determine whether additional data would be needed to better define ranges of input parameters.	Performing disruptive events analyses contributes to iterative sensitivity and uncertainty analyses in TSPA-SR. Seismicity (which can impact WP performance without backfill) for TSPA-SR is treated through uncertainty analysis of nominal performance. Screening of some individual FEPs, as documented in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h), was supported by sensitivity calculations.
General Acceptance Criterion 5 - Parameter values, assumed ranges, test data, probability distributions, and bounding assumptions used in the models are technically defensible and can reasonably account for known uncertainties.	The process followed for the expert elicitation, as described in the framework AMR (CRWMS M&O 2000b, 2000c), ensured that these conditions were met. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs is described in each AMR in Chapters 4, 5, and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMR originators were required to list assumptions and justify data values, ranges, and distributions.
General Acceptance Criterion 6 - Mathematical model limitations and uncertainties in modeling were defined and documented.	Disruptive events analyses related to backfill were limited to those discussed in the specific acceptance criterion section. AMR originators mentioned in the specific acceptance criterion section discuss model limitations and uncertainties in the analysis Section of their AMRs.
General Acceptance Criterion 7 - Primary and alternative modeling approaches consistent with available data and current scientific understanding were investigated and their results and limitations considered in evaluating the subissue.	The process followed for the expert elicitation, as described in the framework AMRs (CRWMS M&O 2000c), ensured that these conditions were met for development of hazard curves for geologic events impacting performance of WPs in the presence of backfill. AMR originators mentioned in the specific acceptance criterion section were required to list assumptions; justify data values, ranges, and distributions; and consider and discuss alternative models in their analysis sections.
General Acceptance Criterion 8 - Model outputs were validated through comparisons with outputs of detailed process models, empirical observations, or both.	Validation of model outputs is an activity performed by TSPA-SR analysis; however, all disruptive events AMRs provide documentation of analyses that may be used when comparison with process models and empirical observations is required. In this manner all disruptive events analyses and the calculation provide support for meeting this criterion.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
General Acceptance Criterion 9 - The structure and organization of process and abstracted models were found to adequately incorporate important design features, physical phenomena, and coupled processes.	Responsibility for the structure and organization of abstracted models in the disruptive events area lies mostly within TSPA-SR activities; however, all disruptive events AMRs provide documentation of analyses that support abstracted models and demonstrate that important design features, physical phenomena, and coupled processes were considered. In this manner all disruptive events analyses and the calculation provide support for meeting this criterion.
Specific Acceptance Criterion 4 - DOE has identified and considered the effects of drip shields (with backfill) on WP lifetime, including extension of the humid-air corrosion regime, environmental effects, breakdown of drip shields and resulting mechanical impacts on WPs, the potential for crevice corrosion at the junction between the WP and the drip shield, and the potential for condensate formation and dripping on the underside of the shield.	The AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000e) considers the effects of drip shields on the distance magma will flow down drifts where it can damage WPs. The AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) feeds data to TSPA-SR that includes the number of WPs compromised considering the effects of drip shields when magma flows down drifts. With drip shields included, rockfall damage to WPs is eliminated from analysis as a disruptive event in TSPA-SR. Damage to drip shields is analyzed in TSPA-SR using ground motion and fault displacement probability information from the PSHA, which is summarized in the AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c).
General Acceptance Criterion 1 - The collection and documentation of data, as well as development and documentation of analyses, methods, models, and codes, were accomplished under approved QA and control procedures and standards.	Each disruptive events AMR and the calculation describe the QA procedures under which it was developed (Chapter 2) and the qualification status of software, models and data used for the analysis (Chapters 3 and 4 for analyses and Chapter 4 for calculation). The Document Input Reference System entries for each AMR captures information used in tracking the completion of qualification and verification activities. For this PMR the QA framework under which it was developed is discussed in Section 1.3.
General Acceptance Criterion 2 - Expert elicitations, when used, were conducted and documented in accordance with the guidance provided in the Branch Technical Position on Expert Elicitation (Kotra et al. 1996) or other acceptable approaches.	The disruptive events AMR that summarizes the results of the PSHA expert elicitation (CRWMS M&O 2000c) that produced hazard curves (for geologic events) used in analysis of drip shield performance contains a description of the conditions under which the elicitation was conducted and documented and references the PSHA document that contains further detail (Wong and Stepp 1998).
General Acceptance Criterion 3 - Sufficient data (field, laboratory, and natural analog) are available to adequately define relevant parameters for the models used to evaluate performance aspects of the subissues.	The process followed for the expert elicitation, as described in the framework AMRs (CRWMS M&O 2000b, 2000c), ensured that these conditions were met for development of hazard curves for geologic events impacting drip shield performance.
General Acceptance Criterion 4 - Sensitivity and uncertainty analyses (including consideration of alternative conceptual models) were used to determine whether additional data would be needed to better define ranges of input parameters.	Performing disruptive events analyses contributes to iterative sensitivity and uncertainty analyses in TSPA-SR. Seismicity (which can impact drip shield performance) for TSPA-SR was treated through uncertainty analysis of nominal performance. Screening of some individual FEPs, as documented in the AMR *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000h), was supported by sensitivity calculations.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
General Acceptance Criterion 5 - Parameter values, assumed ranges, test data, probability distributions, and bounding assumptions used in the models are technically defensible and can reasonably account for known uncertainties.	The process followed for the expert elicitation, as described in the framework AMR (CRWMS M&O 2000c), ensured that these conditions were met. The methodology to ensure meeting this criterion for data from other sources used in disruptive events AMRs is described in each AMR in Chapters 4, 5, and 6 where parameter values, ranges, distributions, and bounding assumptions are described. AMR originators were required to list assumptions and justify data values, ranges, and distributions.
General Acceptance Criterion 6 - Mathematical model limitations and uncertainties in modeling were defined and documented.	Disruptive events analyses related to backfill were limited to those discussed in the specific acceptance criterion section. AMR originators mentioned in the specific acceptance criterion section discuss model limitations and uncertainties in the analysis section of their AMRs.
General Acceptance Criterion 7 - Primary and alternative modeling approaches consistent with available data and current scientific understanding were investigated and their results and limitations considered in evaluating the subissue.	The process followed for the expert elicitation, as described in the framework AMR (CRWMS M&O 2000c), ensured that these conditions were met for development of hazard curves for geologic events impacting performance of drip shields with or without the presence of backfill. AMR originators mentioned in the specific acceptance criterion section were required to list assumptions; justify data values, ranges, and distributions and consider and discuss alternative models in their analysis sections.
KTI: REPOSITORY DESIGN AND THERMAL MECHANICAL EFFECTS (NRC 1999c)	
Subissue 2 - Seismic Design Methodology	The NRC deals with the issues of seismicity and fault displacement through review of DOE Topical Reports (NRC 1999c, p. 23). Discussion of NRC response to DOE Topical Reports (YMP 1997a, 1997b; CRWMS M&O 1999h) comprises the discussion of progress on resolving the subissue. There is only one seismic design that must serve both preclosure and postclosure needs. Disruptive events analyses, which focus on postclosure, contribute to the iterative process of TSPA by which seismic design evolves. It is stated in the Repository Design and Thermal-Mechanical Effects IRSR (NRC 1999c, p. 8) that this subissue provides inputs to the "mechanical disruption of engineered barriers" integrated subissue in the Total System Performance Assessment and Integration IRSR (NRC 2000, Figure 3). That integrated subissue is addressed by disruptive events analyses (see Total System Performance Assessment and Integration Entry in this table). Acceptance criteria for this subissue are provided in Revision 1 of the IRSR (NRC 1998c) and are not discussed again in Revision 2 (NRC 1999c). Discussion of this KTI and its subissues is found in Section 4.6 of this Disruptive Events PMR.
Acceptance Criterion 1 - The staff will find the methodology proposed in the Topical Report adequate for further review if, during an initial acceptance review of Topical Report 2, sufficient technical reasoning is provided for the proposed methodology.	Acceptance criteria are not mapped to components of the subissue and are worded to apply to Topical Reports. Disruptive events AMRs *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g) and *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i) support analysis of fault displacement inputs to the design and PAs. The former examines effects of faulting on engineered barrier elements, and the latter analyzes effects on the natural barrier caused by fracture aperture effects from faulting.

Table 4-12. Summary of the Subissue Acceptance Criteria Addressed by Disruptive Events Analyses and/or the Calculation (Continued)

NRC Technical Acceptance Criteria	PMR Approach and AMR Support
Acceptance Criterion 4 - The staff will find the methodology proposed in the Topical Report adequate for further review if, during an initial acceptance review of Topical Report 2, uncertainties associated with the proposed methodology that would significantly affect or impede the repository design process and development of inputs to PAs have been considered adequately.	Acceptance criteria are not mapped to components of the subissue and are worded to apply to Topical Reports. Disruptive events AMRs *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g) and *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i) support analysis of fault displacement inputs to the design and PAs. The former examines effects of faulting on engineered barrier elements, and the latter analyzes effects on the natural barrier caused by fracture aperture effects from faulting.
Subissue 3 - Thermal-Mechanical Effects	The importance to postclosure analysis of this subissue is in the potential effects on rockfall, particularly seismically induced, from the change in the lithologic stresses caused by the excavation.
Acceptance Criterion 3 - The seismic hazard inputs used to estimate rockfall potential are consistent with the inputs used in the design and PAs as established in DOE's Topical Report 3 (yet to be published).	Disruptive events analyses and the Disruptive Events Workshop held February 9-11, 1999, partially support addressing this acceptance criteria. The workshop addressed refinement of the rockfall model in two areas: determination of rock size distribution and relationship between seismicity and size of rockfall using the Key Block theory; and reassessment of rockfall effects on WP damage. The disruptive events AMR *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000c) summarized the expert elicitation and clarified the key points important for the seismicity component of rockfall. Disruptive events analyses are part of the iterative process by which conceptual models of seismicity and structural deformation evolve for use in PA.

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5. SUMMARY AND CONCLUSIONS

This Disruptive Events PMR summarizes the results of investigations intended to estimate the hazards to the potential repository from events associated with the processes of volcanism and seismicity with structural deformation. As appropriate for this type of analysis, the disruptive events investigations supporting this PMR examined the effects of disruptive events on two designs for the potential repository: (a design with backfill, EDA II [CRWMS M&O 1999a] and a design without backfill, SRSL [CRWMS M&O 2000z]). This Disruptive Events PMR summarizes the results of eight AMRs and one calculation that together analyze the potential consequences of two types of disruptive events: volcanism, which includes both intrusive and extrusive occurrences, and seismicity, which includes vibratory ground motion and its associated structural deformation due to fault displacement (CRWMS M&O 2000a, 2000b, 2000c, 2000e, 2000g, 2000h, 2000i, 2000k, 2000l). Two AMRs summarize the results of expert elicitation projects to support characterization of the volcanic and seismic hazards at Yucca Mountain (CRWMS M&O 2000b, 2000c). These AMRs also present the technical basis for assessing hazards related to volcanism, seismicity, and fault displacement. Four AMRs and the calculation supporting volcanism analysis provide information about parameters needed for TSPA-SR to evaluate the effects, or geologic consequences, of volcanic events. The results of these AMRs improve the analysis of disruptive events consequence through literature research and by interfacing with YMP groups in the EBS and WP disciplines to include consequences for SSCs. Another AMR was a compilation of FEPs screening arguments relevant to disruptive events. These arguments provide, in part, the basis to support determination of the FEPs to be included in the TSPA-SR and those to be excluded from the TSPA-SR (CRWMS M&O 2000h). Two further AMRs, analyzing the effects of fault displacement, support FEPs screening arguments in the disruptive events FEPs AMR.

Disruptive events analysis for TSPA-SR addresses technical concerns expressed by various oversight groups regarding performance of the potential repository during disruptive events. The Disruptive Events PMR summarizes the results of supporting analyses and maps these results to the concerns of the oversight groups, including those contained in NRC IRSRs.

The focus of disruptive events analysis is to provide input to TSPA-SR to support the determination of potential impacts to postclosure repository performance from such events. However, in the end, a single design must serve both preclosure and postclosure purposes with regard to the vibratory ground motion and fault displacement hazards for the site. The following table (Table 5-1) summarizes the contributions that the conclusions of the disruptive events AMRs and the calculation make to constraining processes or developing conceptual models for TSPA-SR as regards eruptive and intrusive events, ground motion events, and fault displacement events.

Table 5-1. Contribution Made by Conclusions of Disruptive Events AMRs and the Calculation to Constraining Processes or Developing Conceptual Models for the TSPA-SR for Volcanic Eruptive and Intrusive Events, Ground Motion Events, and Fault Displacement Events

Disruptive Events AMR or Calculation	Contributions of Conclusions to TSPA-SR Model Development
Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (CRWMS M&O 2000b)	Present technical information to support use of the PVHA (CRWMS M&O 1996) for modeling volcanic hazard. Recalculate volcanic hazard results of the PVHA and extend results to include the probability of eruption conditional on a dike intersection based on two repository footprints and layouts (EDA II and SRSL). Provide appropriate and technically defensible inputs for TSPA-SR. Analyze new data for its potential to necessitate reassessment of PVHA results supporting the conclusion that such a reassessment is not warranted.
Characterize Eruptive Processes at Yucca Mountain, Nevada (CRWMS M&O 2000a)	Improve model for igneous activity hazard by developing technically defensible concepts of volcanic feeder geometry; magma behavior during an eruptive event, including interactions with WPs; and distributions of parameter values.
Dike Propagation Near Drifts (CRWMS M&O 2000e)	Constrain conceptual models for: interaction of the disturbed geologic area around the repository and an ascending dike to conclude that a dike may be deviated by the altered stress field; flow of magma down drifts having drip shields and backfill (EDA II) or no backfill (SRSL) to describe the probable nature of damage to WPs in several different damage zones; magma solidification time and temperature that support conclusions for magma/WP interactions; and gas flow down an idealized drift to support conclusions regarding magma/drift interaction.
Number of Waste Packages Hit by Igneous Intrusion (CRWMS M&O 2000k)	Contribute ranges of parameter values that constrain the distributions for the number of WPs that will encounter the magmatic environment for modeling both eruptive release and groundwater intrusion scenarios to support determination of the amount of waste available for release as a result of volcanic activity. Produce results for two designs, EDA II and SRSL.
Igneous Consequence Modeling for TSPA-SR (CRWMS M&O 2000l)	Construct conceptual models for TSPA-SR to model both eruptive and intrusive volcanic activity, provide the technical basis for parameters used, and suggest the type of code appropriate to model volcanic eruptive events of the type that potentially may occur at the site.
Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada (CRWMS M&O 2000c)	Summarize technical rationale supporting use of the PSHA (Wong and Stepp 1998) for modeling vibratory ground motion and fault displacement hazards.

Table 5-1. Contribution Made by Conclusions of Disruptive Events AMRs and the Calculation to Constraining Processes or Developing Conceptual Models for the TSPA-SR for Volcanic Eruptive and Intrusive Events, Ground Motion Events, and Fault Displacement Events (Continued)

Disruptive Events AMR or Calculation	Contributions of Conclusions to TSPA-SR Model Development
Fault Displacement Effects on Transport in the Unsaturated Zone (CRWMS M&O 2000i)	Provide screening argument to show that fault displacement does not significantly affect transport in the UZ. Provide support for the conclusion that large changes in fault aperture produce small changes in transport behavior between the repository and water table.
Effects of Fault Displacement on Emplacement Drifts (CRWMS M&O 2000g)	Provide screening argument to show that fault displacement does not significantly affect emplacement drifts, WPs, or drip shields.
Features, Events and Processes: Disruptive Events (CRWMS M&O 2000h)	Provide part of the basis for constructing the TSPA-SR model by supplying the technical foundation for including or excluding from TSPA modeling FEPs associated with disruptive events.

In general, the AMRs and calculation supporting disruptive events analysis produce outputs that develop concepts, constrain processes, and recommend parameter distributions and conceptual models for constructing TSPA-SR models that analyze the effects of volcanism, seismicity, and structural deformation. Two disruptive events AMRs (CRWMS M&O 2000g, 2000i) produce results that support screening out analysis of fault displacement hazard in TSPA-SR. Disruptive events analysis results do not contribute directly to analysis of ground motion hazard in the TSPA-SR. However, the overall process of disruptive events analysis during development of the PMR contributes to the iterative development of the potential repository design with regard to vibratory ground motion hazard. The results of disruptive events analysis for this PMR primarily support improvement of consequence modeling for volcanism, except that one AMR provides some improvement in the area of probability analysis by extending the PVHA results to include the probability of an eruption conditional on a dike intersection and by updating the analysis to be appropriate for two repository footprints, EDA II and SRSL. Several volcanism AMRs provide intermediate results that become inputs for other disruptive events AMRs. It is the AMR *Igneous Consequence Modeling for TSPA-SR* (CRWMS M&O 2000l) that produces recommendations to TSPA-SR regarding volcanism. The probability portion of the TSPA-SR hazard analysis for volcanism, ground motion, and fault displacement derives from the results of two expert elicitations. By summarizing the methodology and results of these elicitations, taking into account relevant new information developed in the last few years, two of the disruptive events AMRs (CRWMS M&O 2000b, 2000c) concluded that the two expert elicitations continue to provide an adequate and defensible basis to support TSPA-SR analysis of volcanic and seismic hazard at the potential repository site.

Conclusions regarding the volcanic, vibratory ground motion, and fault displacement hazards at the potential repository site are developed from TSPA-SR analysis that occurs downstream of this PMR. Conclusions about volcanism developed in the AMRs and summarized in this PMR provide the technical basis for parameters used in TSPA-SR including conceptual models of the types of volcanic events to be analyzed, a list of parameters and their value ranges appropriate for analysis of these models, and the basis for selecting the appropriate code to model potential volcanic eruptive events.

Disruptive events are treated in several ways in TSPA-SR calculations. For dose consequence calculations, TSPA-SR includes both nominal performance and disruptive events. Disruptive events are modeled as disruptive scenarios by modifying the appropriate subsystem elements and/or parameters in TSPA-SR to reflect a change that represents a disruption of the nominal condition. Unlike the products of most PMRs, the Disruptive Events PMR does not summarize a process model that was abstracted into the TSPA-SR. Disruptive events analyses and the calculation produce values for parameters such as the quantity of radionuclides available from an igneous intrusion groundwater release for transport modeling in the UZ flow model.

For TSPA-SR, seismicity is treated through uncertainty analysis of nominal performance, meaning it is treated as part of the nominal case. Screening for including in or excluding from TSPA-SR some individual disruptive events FEPs is supported by sensitivity calculations. The seismic events considered for TSPA-SR are vibratory ground motion and fault displacement. These effects are characterized as annual probabilities of exceeding specified levels of ground motion or fault displacement. For preclosure, the ground motion and fault displacement characteristics are used to develop seismic design inputs for repository structures. For postclosure, ground motion is considered in terms of increased likelihood (frequency) of rock falls in the emplacement drifts. Fault displacement effects are considered in terms of disruptions to components of the EBS and effects on the transport of radionuclides in the UZ.

The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) summarizes the expert elicitation PVHA (CRWMS M&O 1996), discusses new data, and clarifies the rationale for DOE conceptual models of volcanism and the resultant hazard. The analysis of new data concludes that they would not significantly impact the results of the PVHA. The AMR *Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000g) examines the potential for disruption by faulting of EBSs including drifts, WPs, and drip shields, in spite of avoiding faults by using setbacks during design. The AMR constrains processes and states that calculated stress levels are not considered detrimental to drift stability and that drip shields and WPs are not likely to experience significant damage due to these stress levels. The AMR *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000i) examines the potential for significant changes in hydrologic properties due to fault displacement. The AMR constrains processes and states that large changes in fracture aperture correlate to small changes in transport behavior, suggesting that models for TSPA-SR may exclude the effects of fault displacement on UZ transport.

This Disruptive Events PMR provides support for the conclusion that the analyses and calculation on which this report is based were conducted and documented following appropriate QA procedures and other project requirements, and that they produced results that are adequate for the intended purpose of supporting analysis during TSPA-SR modeling of the potential hazards of disruptive events.

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APPENDIX A

AN ESTIMATE OF FUEL-PARTICLE SIZES FOR PHYSICALLY DEGRADED SPENT NUCLEAR FUEL FOLLOWING A DISRUPTIVE VOLCANIC EVENT THROUGH THE REPOSITORY

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Appendix A is an edited excerpt from an analysis performed within the AMR *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2000o, Appendix A, Attachment 1). This analysis is the basis for waste particle sizes used in the analysis of the volcanic eruptive release scenario in disruptive events analysis. For citations and other support for the technical statements and values presented in this attachment see the original text in the Waste Form FEPs AMR.

A.1 INTRODUCTION

This document addresses estimates of particle-size distributions for SNF exposed to a potential disruptive magmatic event through the potential repository at Yucca Mountain, Nevada. The distribution was to consider mechanical and chemical degradation of the fuel at the time of the disruptive event. The following discussions for waste particle diameter are based on investigations and data generated by Argonne National Laboratory. The disruptive event may occur at any time, but the estimated extent of fuel degradation that will have occurred at the time of the event is not addressed here. The following discussion is based on laboratory examinations of commercial SNFs, which were conducted for purposes outside the realm of understanding particle size. There is no statistical information available for the distribution of particle sizes caused by the disaggregation and grinding of spent UO_2 fuels in the laboratory. There is a similar paucity of data for oxidized and corroded fuels as well.

The following discussion concerns commercial, spent UO_2-based fuels.

A.2 FUEL DEGRADATION

The three states of fuel degradation can be defined as (1) unaltered fuel (i.e., uncorroded and unoxidized), (2) dry-air oxidized fuel, and (3) aqueous-corroded fuel. Particle sizes are estimated for each below.

A.2.1 Unaltered Fuel (Uncorroded and Unoxidized)

Unaltered SNF shows a range of physical characteristics that depend largely on fission-gas release and possibly burnup; however, there is no clear understanding of the relationship between such parameters and the relative ease with which fuel may fragment under stress or the grain sizes that might result from fragmentation. Fission-gas release appears to be a crucial parameter affecting fuel microstructure, including grain growth, a characteristic that will strongly impact the distribution of fuel-particle sizes from a fuel following exposure to a disruptive volcanic event.

When crushing spent UO_2 fuel during the preparation of corrosion studies on fuel being conducted at Argonne National Laboratory, it was found that reducing the particle sizes of a fuel of moderate burnup (~ 30 MW d/kg-U) was readily achieved by initial crushing with a Platner mortar and pestle followed by a few minutes of grinding in a stainless-steel-ball mill. The distribution of particles sizes obtained after crushing and milling was approximately bimodal, with numerous large (>0.015 cm diameter) fragments and material less than 0.0045 cm, which subsequent scanning electron microscope examination revealed to be approximately single fuel grains (~0.0020 cm diameter). A relatively small amount of the fuel particles were between ~ 0.0045 cm and 0.015 cm in diameter. No attempt was made to estimate the relative distribution of these three particle sizes during the initial grinding; however, following the sample preparation procedure, in which the largest fragments (>0.0075 cm) were crushed and milled a second time, the final distribution of particle sizes obtained after preparation for the Argonne National Laboratory tests given in Table A-1 was achieved.

Table A-1. Final Distribution of Fuel-Particle Sizes after All Grinding Cycles (Argonne National Laboratory Tests)

Size Fraction (Particle Diameter)	Mass (gram)	Relative Amount*
<0.0045 cm (average~0.0020 cm) (mostly single fuel grains)	2.3252	81%
0.0045 to 0.015 cm	0.3063	11%
>0.015 cm	0.2520	9%

NOTE: *Total relative amount exceeds 100% due to rounding.

Several powders of spent UO_2 fuels were prepared for flow-through dissolution studies conducted at Pacific Northwest National Laboratory by crushing and grinding de-clad segments. Not all fuels show identical particle-size distributions. Several fuels display very small particles—on the order of 0.001 cm or less. Although scanning electron microscope examinations of the Argonne National Laboratory fuel grains revealed relatively few particles of ~ 30 MW d/kg-U fuel with sizes less than single grains, the Pacific Northwest National Laboratory results from a wider variety of fuel types necessitates shifting the potential distribution of grain sizes to smaller particle sizes than that estimated from the ~ 30 MW d/kg-U results alone. We consider here that 0.0001-cm diameter particles represent a reasonable lower limit on particle sizes for all unaltered fuels exposed to a disruptive volcanic event.

A.2.2 Dry-Air Oxidized Fuel

Spent UO_2 fuel that has been oxidized in the absence of moisture may form a series of oxides, with concomitant degradation of the integrity of the fuel meat. Oxidation up to a stoichiometry of $UO_{2.4}$ leads to volume reduction of the UO_2 matrix. This can open grain boundaries and may result in the disaggregation of the fuel into single fuel grains. Further oxidation to U_3O_8 and related oxides results in a large volume expansion and potentially extreme degradation of the fuel into a powder with particle sizes less than one micrometer in diameter. Scanning electron microscope examination of spent fuel oxidized to approximately U_3O_8 indicates particle sizes of approximately 2.5 micrometers (0.00025 cm diameter) with lower limits of approximately 0.5 micrometers (0.00005 cm diameter), with larger particles ranging up to approximately 50 micrometers diameter (0.005 cm) (Table A-2). An estimate of the larger limit on the range of particle sizes is more difficult to make with much certainty. Based on qualitative observations of ~ 30 MW d/kg-U fuel following preparation for the Argonne National Laboratory corrosion studies, an upper limit of 0.0005 cm diameter is chosen (Table A-2).

Table A-2. Estimated Fuel-Particle Sizes*

Degradation State	Mean (cm diameter)	Range (cm diameter)
Unaltered fuel	0.0020	0.0001 to 0.050
Oxidized in dry air	0.00025	0.00005 to 0.0005
Corroded fuel	0.0002	0.00005 to 0.001

NOTE: *Sizes indicate particle diameters.

A.2.3 Aqueous-Corroded fuel

Scanning electron microscope examinations of corroded spent fuel following interaction with simulated groundwater at 90°C were performed. The grain sizes of uranium (VI) alteration products on corroded fuel commonly reach 0.01 cm; however, considering the physical properties of uranium (VI) compounds, these phases are similar to gypsum or calcite in terms of hardness and fracture toughness. Therefore, a powerful eruptive event will probably fragment nearly all of the larger crystals of secondary U phases, which is why a smaller upper limit of 0.001-cm diameter is chosen for the range of particle sizes for aqueous-corroded fuel (Table A-2). The lower value for the particle-size range is based on the scanning electron microscope examinations that demonstrate the extremely fine-grained nature of many alteration products, with crystal dimensions as small as 0.5 micrometers or less (≤0.00005 cm).

Suggested particle-size ranges and average values for particle sizes of light-water-reactor fuels are listed in Table A-2. No firm statistical foundation underlies the averages or ranges listed in Table A-2; however, based on sources, these averages are considered appropriate. Limiting values for the ranges are less well constrained, perhaps, but it is likely 80 to 90 percent of the fuel particles will fall within the ranges reported in Table A-2.

Based on our current level of understanding, it seems reasonable to treat both categories of altered fuel (dry-air oxidized and aqueous-corroded) almost the same, since their estimated particle sizes are not very different from each other. The altered fuel is substantially more friable than (most) unaltered fuel, with size distributions that may be skewed to quite small sizes.

A.3 OTHER TYPES OF SPENT FUEL

In addition to commercial SNF, which constitutes the vast majority of the fuel inventory destined for permanent disposal, there are additional fuel types that may exhibit physical properties that are quite distinct from those of commercial SNF. These “other” spent fuels include those from research reactors, military-use reactors, and other sources. They are highly variable in their physical characteristics, include materials from metals to carbides, and may be in a variety of forms, from ingots to granules. No attempt is made here to estimate potential particle sizes for this broad category of fuel types. Furthermore, there are too few data currently available on the physical properties of these fuels following physical and/or chemical degradation that may occur in the potential repository following their disposal.

A.4 DEFENSE HIGH-LEVEL RADIOACTIVE WASTE GLASS

Whereas HLW glass will constitute a large volume fraction of the total volume of waste in the potential repository, it is not the major contributor to total activity. HLW glass is probably best treated in a manner similar to the tuff rock, which also consists of a large volume of glass. Similarly, an intrusive, rapidly cooling magma is likely to be glassy as well.